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ABBREVIATIONS

a.—article(s), report(s)

fn.—footnote

r.—reference, referred to

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BROADENING THE HIGHWAY PROGRAM

By THOS. H. MACDONALD, Chief, Bureau of Public Roads[1]

TO AN AUDIENCE composed of those engaged in the actuality of highway improvement, including all of its phases, it is not necessary to call attention to the fact that the broadening of our national highway program is not a probability of the future but is a policy which has already attained definition and considerable stature.

Since July 1933, more than 11,000 individual projects have been placed under way in the Public Works highway programs. That 60 percent of these projects are off the Federal-aid highway systems of the States as they existed at the start of the program roughly measures the velocity attained in broadening the program through liberalizing the Federal highway policies. These projects off the Federal-aid highway system provide for its extension at both its extremes—on the one hand the feeder roads of the rural districts and on the other the principal thoroughfares of cities and towns. The addition of these two classes of roads and streets to the federally supported highway program is not the only element of this broadened highway policy structure. The elimination of grade crossings without railroad participation in the financing, the landscaping and planting of roadsides, and the building of footpaths, are other, but not all, of the worthy additions to the rapidly progressing highway policies.

Because of this constantly changing picture it becomes highly important to examine critically what we are doing, that we may project a course into the future, safeguarded from at least those hazards which experience has already uncovered. The easiest possible mistake is the failure to visualize the dimensions of a problem so vast as that of adequate road and street improvement in an area more than 2,000 miles wide and more than 3,000 miles long. The number of people alone that must be brought into a common and efficient operating organization goes far beyond ordinary conceptions. Here is a field in which faith, good will, and devotion to the public service will produce results beyond the reach of any other power.

The response that the Nation has had from highway officials, contractors, and material producers is of so high a quality generally that the departures stand out conspicuously as exceptions to a record of which the Nation can be proud.

Passing for the moment the employment aspect of the highway program, which is the cause underlying the enlarged undertakings in this field supported with Federal funds, it appears desirable to review briefly the experience of the years through which we have come to the present stage of highway development, that in the broadening of the program we may yet adhere to sound policies.

As a matter of history, between the time of abandonment of National and State projects undertaken in the early days before the advent of the railroads and about 1890 the localities were in control and there was no conception of planning highways on a State-wide basis.

The first State highway departments were established to assist the localities rather than to undertake, as a State policy, the building of a State highway system. In the Federal legislation of 1916 there was still no conception of the setting up of a plan of systematic highway improvement. The first requirement of this character in modern Federal legislation came with the legislation of 1921, when, as a first undertaking, the application of Federal funds was limited to a system of interstate and intercounty roads consisting of not more than 7 percent of the total rural road mileage.

In the decade and a half now intervening, marked by the improvement of some 200,000 miles of highways in part with the aid of Federal funds, this restricted system was rigidly maintained as a first objective. Year after year in both State and Federal legislative bodies there were innumerable drives to spread the application of the cooperative Federal and State funds more widely. Credit is due our law-making bodies that the principle was preserved intact for a period sufficient to establish communication over highways on this skeleton framework, consisting of a small percentage of our total highway mileage, but so carefully selected that it is now possible to travel from one end of the country to the other with a degree of speed and comfort—not that the building of long distance roads was the prime objective, for highway traffic is now and will remain primarily local.

TERMINATION OF PIONEER PHASE BRINGS NEW PROBLEMS IN ROAD BUILDING

Our long-distance highways have come as a byproduct of the careful planning and coordination of the most important highways within and between the States. This deliberate policy of restriction has established reasonably universal communication over the roads within the minimum possible mileage. No other course would have made it possible, in so short a time, to create the main highway system capable of serving, if imperfectly, so large a part of the total of highway traffic. No other course would have so quickly joined with reasonably serviceable highways so many of our towns and cities, or placed a usable road within so short a distance of so many of our farms. No other course would have made it possible for the average American citizen and his family, with the modern moderately priced car, to become acquainted with neighboring States and with the more distantly located national parks and forests, or would have opened to him so many other recreational and educational opportunities.

No other course would, within this relatively short period, have brought us to the point where we are enabled to broaden the highway program soundly and with good effect. We can, and we unquestionably will continue the building of Federal roads extending from the improved main network into the farm communities. Every such road will bring to the land it serves not only its own important benefits but the multiplied benefits of the arterial system to which it becomes thus attached. Had the building of these feeders been undertaken before the improvement of the main system, such policy would have been comparable to the digging of the laterals of a drainage system before the opening of the outlet channel.

The principal difficulty which we encounter in this broadening of the highway program is the varying degrees or stages to which the several States have advanced. In certain States conservative highway officials may still point to the considerable mileage of the more important roads still inadequately improved. For these States the time to take on responsibility of an additional mileage will be at some future period when the main system is more fully improved. There are a considerable number of States in which this is undoubtedly the correct attitude at this time, and any future Federal legislation must be sufficiently flexible to take such situations into account.

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[1] Paper presented Jan. 22, 1935, at the 32d annual convention of the American Road Builders' Association held in Washington, D. C.

The broadened program of the future must provide for the progressive development of the main roads in which we have now a tremendous investment. Otherwise, they will be found inadequate for the greater traffic which their very improvement has developed. Many things are yet undone on the main road systems, things which have been deliberately passed in the doing of the pioneer work that has engaged us up to now.

On a very large mileage of main roads the improvement of today must be regarded as providing only the minimum of service. Not only the density, but the speed of traffic has been so stepped up that the project designed for conditions existing not more than 5 years ago has now fallen below the acceptable and safe minimum. Such essential but in the past necessarily deferred details as the elimination of railroad grade crossings, replacement of narrow bridges, and the general construction of footpaths where justified, are important elements which must be continued in this broadened highway program.

The provision for the separation of more than 500 dangerous grade crossings is a real achievement of the present going program. Added to this is the construction of adequate roads around as well as through cities. Through the special highway-user taxes the people of the cities have contributed in some States the major part of the funds used for the upbuilding of our rural main road system. City residents can now with justice claim more attention.

All of these are essential concomitants of the necessary provision for our developing highway transportation, things which have been for the most part omitted from the simpler program of the past. Hence it is clear that the broadened national highway program consists not merely in the inclusion of additional mileage of local or feeder roads or city streets justifying improvement, but also includes a general lifting of the aim of the improvement effort to include objectives, the relative importance of which has increased as we have approached the first goal of "getting the traffic through" which has occupied so large a place in the past perspective.

To characterize most of what has been done thus far as a pioneer effort is not to detract from the magnificence and speed of the accomplishment that stands to the credit of the cooperative action of the State and Federal governments. It is desired only to place past accomplishments in their true relation to what remains to be done. A clear understanding of this relation suggests the answer to those whose conception has not yet been lifted to the new level of highway facility which has become possible and desirable. Even these suggestions do not touch upon the development which it is evident is not far around the corner, of highways conceived primarily upon the interstate or national basis in those sections where the population density and traffic, already developed on the inter-city roads, point to the necessity of new highways or parkways outside of the congested areas and high-priced suburban developments.

BALANCED PROGRAM MUST BE FORMULATED

In a moderate program of carefully conceived highways of this character lies not only the possibility of providing for recreational travel in a manner not possible upon our most heavily traveled roads, but the provision for the enlargement of recreational facilities within easy reach of our industrial population, and in some cases, as with the Shenandoah Parkway of the Blue Ridge Mountains, the providing of a new climate to a large population sweltering in the summer heat and humidity of the valleys. Here is an example of the possibility of bringing to the average citizen and his family the benefits of a cooler and more helpful climate and more beautiful surroundings by placing them within easy reach of his home. The flora in the higher elevations of the Smoky Mountains National Park is that of Labrador. Highways are the gateway to a climate otherwise denied to the majority who have neither the time nor the means to travel to the north country. So the ending of the pioneer period brings us to new and more difficult decisions. The question is not that of giving or denying highways to the rural districts or to the cities. It is the far more complex one of balancing the program within the reasonably supportable expenditures in such a ratio between these different and desirable objectives so that consistently there will be the greatest benefit to the greatest number.

The various classes of improvements, the extent to which each shall be undertaken, not only within the highway field itself but in the wider field of coordination of highways and other transportation facilities, all accent the complexity of our future policies and program, but there are many circumstances which determine that quite definite decisions shall be made. One of the principal of these is the transfer of complete authority over all highways to the highway departments, a movement that will doubtless progress with gathering momentum at the coming State legislative sessions. Of the benefits to be obtained by such transfer there is little doubt, but they bring with them a danger if transfer of responsibility is not accompanied by commensurate provision of income.

The tendency to divert from highway uses revenues intended for such purposes and no other is acute. The persistence of unemployment which has prompted large Federal appropriations has unfortunately been met by diversion from highway needs of the special revenues accruing from highway use. From the employment angle alone, nothing is gained by such diversion, since the dollar spent for highway work reaches as far to relieve unemployment as any other expenditures that could possibly be made.

Adjustments of the future highway program to meet changing economic conditions forced upon the railroads, and the improvement of the highways to fit the presumed program of the railroads which appears to contemplate faster and lighter trains, are as important as the development of highways to take over traffic where unprofitable branch line operations are abandoned.

Confronted by the unavoidable necessity of broadening the highway program in many directions and recognizing the demand for prompt decision on numerous questions, the inevitable conclusion is that further

(Continued on p. 11)

A STUDY OF THE LIVES OF BRICK-ON-CONCRETE PAVEMENTS[1]

ANALYSIS OF MORTALITY OF BRICK-ON-CONCRETE PAVEMENTS IN DES MOINES, IOWA

By **ANSON MARSTON**, Senior Dean of Engineering, Iowa State College

Owing to dearth of data of the actual service lives of different types of highway pavements, present estimates of their probable lives are based mostly on opinions instead of on facts.

This paper presents the results of a "mortality-curve" study of the actual service lives of brick-on-concrete pavements in the city of Des Moines, Iowa, as indicated by their actual mortality data during the years 1909-28, inclusive. The collection, arrangement, and calculation of the mortality data are explained and illustrated. The resulting "mortality curves" are given; and the method of using them to assist in estimating the probable lives of similar pavements still in service is explained.

Similar studies of rural-highway pavement actual service lives, in at least four different States, are being undertaken, in a cooperative highway research project, by the U. S. Bureau of Public Roads and the Iowa Engineering Experiment Station.

THERE is at present so nearly a complete lack of collected and studied reliable data of the actual service lives of different types of highway pavements that our knowledge of the probable lives of the billions of dollars worth of existing pavements is merely what we can surmise from the opinions of highway engineers. Even when collected by such respected authorities as the Interstate Commerce Commission, and even when expressed by such competent engineers as those employed by our State highway commissions and our large cities, engineering opinions upon pavement lives have a range of from about 10 to about 40 years for concrete, brick, and asphalt, with corresponding variations for other types. Manifestly, estimates based upon opinions which vary 400 percent cannot be considered reliable.

Pavement life is one of the most essential of the factors whose numerical values must be known in order to determine the annual costs of highway systems and/or the costs of different classes of highway services. Correct records of both of these are especially important at the present time, in highway economics in deciding upon correct highway policies, and in highway accountancy in developing and using satisfactory uniform highway accounting systems.

The fact that quite a large mileage of rural highway pavements built since the World War has now reached service ages of 10 to 20 years combines with the need to substitute facts for guesses of pavement life to make the present an opportune time to collect and study, by the best and most advanced methods, a large amount of reliable data of the actual service lives of rural highway pavements.

ACTUAL RETIREMENTS OF BRICK-ON-CONCRETE PAVEMENTS AT DES MOINES, IOWA, STUDIED BY USE OF MORTALITY CURVES

In his paper on the "Engineering Valuation of Highway Systems",[2] presented one year ago, the author explained briefly the "mortality-curve" method of studying actual retirement data of different kinds of industrial property. From January to June 1934, Mr. J. Phil Starbuck,[3] of Ames, Iowa, a graduate student working under the direction of Mr. Robley Winfrey and the author, made a detailed study of the actual retirement data of all brick-on-concrete and brick-on-sand pavements in Des Moines, Iowa, using the "mortality curve" method. The newest brick-on-sand pavements found had been built in 1899, so that Mr. Starbuck's data did not include their retirements at ages of 1 to 9 years. For this reason, only the data for brick-on-concrete pavements will be presented in this paper.

By careful search of the city paving records, Mr. Starbuck obtained and tabulated for each year, 1909 to 1928, inclusive, data of:

1. The actual pavement retirements each calendar year, classified by service ages.
2. The total amounts of pavement of each age actually in service each calendar year.

The retirement data were tabulated, in square yards, as shown in table 1 for the years 1919 to 1928, inclusive; and were averaged to give the average annual retirements for each age. Similarly, the amounts of pavement of each service age in service during each calendar year were tabulated and averaged as shown in table 2. Finally, the averaged annual pavement retirements and pavements in service each calendar year were tabulated and calculated as shown in table 3, to give the calculated mortality survivor-curve data in columns 5 and 7—column 5 for the "annual rate method" and column 7 for the "individual unit method."

Computations corresponding to those illustrated in tables 1, 2, and 3, for 1919 to 1928 were made for the 1909–18 and the 1909–28 brick-on-concrete pavement mortality data.[4] The mortality "survivor-curve" data thus obtained by the "annual rate method" have been plotted and are shown in figure 1, herewith, together with the "individual unit" survivor curve for the period 1909–18.

The "annual rate method", the final computations by which are illustrated in columns 2, 3, 4, and 5 of table 3, is the correct method for computing mortality "survivor curves" of different classes of industrial property. It correctly takes into account all the pavement in service each year. The "individual unit method", whose final computations are illustrated in columns 6 and 7 of table 3, takes into account only

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[1] Paper presented before annual meeting of the Highway Research Board at Washington, D. C., December 1934.

[2] Proceedings, Highway Research Board, vol. 13, p. 43.

[3] In his progress report to the author, June 1934, Mr. Starbuck acknowledged indebtedness for assistance to John M. Tippee, city engineer, and C. C. Green, office engineer, both of Des Moines, Iowa, to John C. Hultquist, a fellow graduate student, and to Robley Winfrey and E. R. Davis of the staff of the Engineering Experiment Station, Iowa State College.

[4] All Mr. Starbuck's tables in [illegible] been recomputed and corrected by Mr. E. R. D[illegible]

Table 1.—*Brick-on-concrete pavement retirements, Des Moines, Iowa, 1919–28*

Age interval, years	Square yards retired during each age interval											Average per year, square yards
	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	Total	
0-½												
½-1½												
1½-2½												
2½-3½												
3½-4½	649										649	64.9
4½-5½												
5½-6½												
6½-7½												
7½-8½					5,143						5,143	514.3
8½-9½					2,029						2,029	202.9
9½-10½	4,214				510						4,724	472.4
10½-11½			12,762								12,762	1,276.2
11½-12½	735										735	73.5
12½-13½												
13½-14½												
14½-15½												
15½-16½	1,006				577	2,951					4,534	453.4
16½-17½					2,624		6,150				8,774	877.4
17½-18½	518			7,846							8,364	836.4
18½-19½					1,156						1,156	115.6
19½-20½												
20½-21½									1,670		1,670	167.0
21½-22½	18,591							1,461			20,052	2,005.2
22½-23½												
23½-24½												
24½-25½				5,942	284						6,226	622.6
25½-26½	1,152										1,152	115.2
26½-27½												
27½-28½												
28½-29½												
29½-30½							1,947		11,103		13,050	1,305.0
30½-31½								1,916		9,016	10,932	1,093.2
31½-32½									1,122		1,122	112.2
32½-33½												

Table 2.—*Brick-on-concrete pavements in service, Des Moines, Iowa, 1919–28*

Age interval, years	Square yards in service at beginning of each age interval											
	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	Total	Average
0-½	65,014	37,342	31,643	51,636	11,451	78,741	90,499	99,054	46,444	67,315	579,139	57,913
½-1½	65,014	37,342	31,643	51,636	11,451	78,741	90,499	99,054	46,444	67,315	579,139	57,913
1½-2½	16,529	65,014	37,342	31,643	51,636	11,451	78,741	90,499	99,054	46,444	558,353	55,835
2½-3½	69,238	46,529	65,014	37,342	31,643	51,636	11,451	78,741	90,499	99,054	581,147	58,114
3½-4½	56,208	69,238	46,529	65,014	37,342	31,643	51,636	11,451	78,741	90,499	538,301	53,830
4½-5½	13,131	55,559	69,238	46,529	65,014	37,342	31,643	51,636	11,451	78,741	460,284	46,028
5½-6½	21,580	13,131	55,559	69,238	46,529	65,014	37,342	31,643	51,636	11,451	403,123	40,312
6½-7½	7,087	21,580	13,131	55,559	69,238	46,529	65,014	37,342	31,643	51,636	398,759	39,875
7½-8½	5,346	7,087	21,580	13,131	55,559	69,238	46,529	65,014	37,342	31,643	352,469	35,246
8½-9½	66,838	5,346	7,087	21,580	13,131	50,416	69,238	46,529	65,014	37,342	382,521	38,252
9½-10½	21,718	66,838	5,346	7,087	21,580	11,102	50,416	69,238	46,529	65,014	364,868	36,486
10½-11½	52,732	17,504	66,838	5,346	7,087	21,070	11,102	50,416	69,238	46,529	347,862	34,786
11½-12½	35,859	52,732	17,504	54,076	5,346	7,087	21,070	11,102	50,416	69,238	324,430	32,443
12½-13½	13,460	35,124	52,732	17,504	54,076	5,346	7,087	21,070	11,102	50,416	267,917	26,791
13½-14½	21,012	13,460	35,124	52,732	17,504	54,076	5,346	7,087	21,070	11,102	238,513	23,851
14½-15½	24,459	21,012	13,460	35,124	52,732	17,504	54,076	5,346	7,087	21,070	251,870	25,187
15½-16½	16,503	24,459	21,012	13,460	35,124	52,732	17,504	54,076	5,346	7,087	247,303	24,730
16½-17½	19,060	15,497	24,459	21,012	13,460	34,547	49,781	17,504	54,076	5,346	254,742	25,474
17½-18½	6,490	19,060	15,497	24,459	21,012	10,836	34,547	43,631	17,504	54,076	247,112	24,711
18½-19½	1,708	5,972	19,060	15,497	16,613	21,012	10,836	34,547	43,631	17,504	186,380	18,638
19½-20½	9,964	1,708	5,972	19,060	15,497	15,457	21,012	10,836	34,547	43,631	177,684	17,768
20½-21½	36,059	9,964	1,708	5,972	19,060	15,497	15,457	21,012	10,836	34,547	170,112	17,011
21½-22½	61,093	36,059	9,964	1,708	5,972	19,060	15,497	15,457	21,012	9,166	194,988	19,498
22½-23½	50,265	42,502	36,059	9,964	1,708	5,972	19,060	15,497	13,996	21,012	216,035	21,603
23½-24½	29,968	50,265	42,502	36,059	9,964	1,708	5,972	19,060	15,497	13,996	224,991	22,499
24½-25½	15,657	29,968	50,265	42,502	36,059	9,964	1,708	5,972	19,060	15,497	226,652	22,665
25½-26½	5,486	15,657	29,968	50,265	36,560	35,775	9,964	1,708	5,972	19,060	210,415	21,041
26½-27½		4,334	15,657	29,968	50,265	36,560	35,775	9,964	1,708	5,972	190,203	19,020
27½-28½	4,306		4,334	15,657	29,968	50,265	36,560	35,775	9,964	1,708	188,537	18,853
28½-29½		4,306		4,334	15,657	29,968	50,265	36,560	35,775	9,964	186,829	18,682
29½-30½			4,306		4,334	15,657	29,968	50,265	36,560	35,775	176,865	17,686
30½-31½				4,306		4,334	15,657	28,021	50,265	25,457	128,040	12,804
31½-32½					4,306		4,334	15,657	26,105	50,265	100,667	10,066
32½-33½						4,306		4,334	15,657	24,983	49,280	4,928
33½-34½							4,306		4,334	15,657	24,297	2,429
34½-35½								4,306		4,334	8,640	864
35½-36½									4,306		4,306	430
36½-37½										4,306	4,306	430
37½-38½												

TABLE 3.—*Calculation of survivor curve for brick on concrete pavements, Des Moines, Iowa, 1919–28*

Age interval	Annual rate method: Average retirements during age interval	Annual rate method: Average area in service at beginning of age interval	Annual rate method: Annual rate of retirement	Annual rate method: Surviving at beginning of age interval	Individual unit method[1]: Sum of average retirements	Individual unit method[1]: Surviving at beginning of age interval
1	2	3	4	5	6	7
Years	*Sq. yds.*	*Sq. yds.*	*Percent*	*Percent*	*Sq. yds.*	*Percent*
0-½		57,913		100.00	10,307	100.00
½-1½		57,913		100.00	10,307	100.00
1½-2½		55,835		100.00	10,307	100.00
2½-3½		58,114		100.00	10,307	100.00
3½-4½	64.9	53,830	0.121	100.00	10,307	100.00
4½-5½		46,028		99.87	10,242	99.37
5½-6½		40,312		99.87	10,242	99.37
6½-7½		39,875		99.87	10,242	99.37
7½-8½	514.3	35,246	1.459	99.87	10,242	99.37
8½-9½	202.9	38,252	.530	98.42	9,728	94.38
9½-10½	472.4	36,486	1.295	97.90	9,525	92.41
10½-11½	1,276.2	34,786	3.669	96.63	9,052	87.82
11½-12½	73.5	32,443	.227	93.08	7,776	75.44
12½-13½		26,791		92.87	7,703	74.73
13½-14½		23,851		92.87	7,703	74.73
14½-15½		25,187		92.87	7,703	74.73
15½-16½	453.4	24,730	1.833	92.87	7,703	74.73
16½-17½	877.4	25,474	3.444	91.17	7,249	70.33
17½-18½	836.4	24,711	3.385	88.03	6,372	61.82
18½-19½	115.6	18,638	.620	85.05	5,536	53.70
19½-20½		17,768		84.52	5,420	52.58
20½-21½	167.0	17,011	.982	84.52	5,420	52.58
21½-22½	2,005.2	19,498	10.284	83.69	5,253	50.96
22½-23½		21,603		75.09	3,248	31.51
23½-24½		22,499		75.09	3,248	31.51
24½-25½	622.6	22,665	2.747	75.09	3,248	31.51
25½-26½	115.2	21,041	.547	73.02	2,625	25.47
26½-27½		19,020		72.62	2,510	24.35
27½-28½		18,853		72.62	2,510	24.35
28½-29½		18,682		72.62	2,510	24.35
29½-30½	1,305.0	17,686	7.379	72.62	2,510	24.35
30½-31½	1,093.2	12,804	8.538	67.26	1,205	11.69
31½-32½	112.2	10,066	1.115	61.52	112	1.08
32½-33½		4,928		60.84		
33½-34½		2,429		60.84		
34½-35½		864				
35½-36½		430				
36½-37½		430				

[1] The method will be understood if it is observed that column 6 represents cumulative totals of column 2 beginning at the bottom of the column. Column 7 represents the corresponding percentages, taking the total retirements observed as 100 percent.

those pavements actually retired, and hence gives entirely too small percentages of survivors at different service ages and entirely too small average life of pavements. For example, the average life for the years 1909–18 by the "individual unit method" was only 17 years; whereas the correct average life indicated by the mortality data was 22 years, as shown by the "annual rate method." It should be noted that estimates of average pavement lives based largely upon first or comparatively early retirements are quite likely to be too small.

Computations of average lives of pavements.—The average life of a pavement for which a mortality survivor curve like those in figure 1 is available must be found by computing the area under the survivor curve (usually divided for this purpose into strips each, except the first, 1 year wide) and dividing it by 100 (since the survivors are platted in percents).

As explained in the paper on the "Engineering Valuation of Highway Systems", already referred to, the Iowa Engineering Experiment Station has developed some 13 "mortality type curves", which seem to pretty well cover the usual range of the mortality characteristics of the different kinds of industrial property. Four of these are "left mode" curves, designated L_1, L_2, L_3, L_4; five are "symmetrical", S_1, S_2, S_3, S_4, S_5, and four are "right mode", R_4, R_3, R_2, R_1.

By trial, it was found that the mortality data of brick-on-concrete pavements in Des Moines, 1909–18 fitted curve S_2, those for 1919–28 fitted S_1, and those for 1909–28 also fitted S_1, all as shown in figure 1. It therefore appears that mortality type curve S_1 is the one to use in estimating the probable life of any particular stretch of concrete-on-brick pavement still in service in Des Moines.

The average lives, in years, indicated by the mortality survivor curves in figure 1 are 22 for the retirements of 1909–18, 36 for the retirements of 1919–28, and 28 for the entire 20 years retirements, 1909–28. Information is lacking about the traffic intensities, differences in design, changes in retirement policies, and other circumstances which would completely explain these variations in average life. It is permissible to point to the improvements in pavement design and construction in later years and to the probability that the heavy-traffic streets were more apt to be paved first, as circumstances which may partially explain the apparent increase in the average life of the pavements retired in the later years.

PAVEMENT MORTALITY CURVES USEFUL IN FORECASTING THE PROBABLE LIVES OF PARTICULAR EXISTING PAVEMENTS

The mortality type curves which fit the actual pavement mortality data of particular kinds of pavements (see fig. 1) can be of great service in forecasting the probable lives of particular existing pavements.

The mortality type curves are "generalized" by stating and platting their service ages in percents of average life.

Just as average life can be computed by dividing the entire area under the mortality curve by 100, so the expectancy of the average survivor at any age can be computed by dividing the area under the mortality curve to the right of the age ordinate by the percentage of survivors at the age. Expectancy plus service age is probable life; and "probable life curves", computed in this manner, can be platted on the same diagram as survivor curves.

Table 4 shows the results of computations of expectancies and probable lives of the average survivor at different service ages for mortality type curve S_1.

Figure 2 shows mortality type S_1, "survivor" and "probable life" curves platted on the same diagram and "generalized" by platting service ages in percentages of average life.

The use of figure 2 in forecasting the probable lives of particular pavements will be illustrated by two (imaginary) cases of brick-on-concrete Des Moines pavements, of which the average life has been found to be 28 years.

Case 1.—A brick-on-concrete pavement on an important business street. The service age is 21 years. The present [illegible] condition is poor, in comparison with the average condition of 21 year-old brick-on-concrete payments in the city. The traffic is much heavier than average traffic on such pavements.

In figure 2, follow the 75-percent age ordinate up to the survivor curve, proceed horizontally across to the probable-life curve and thence vertically down (all as indicated on fig. 2 by broken lines and arrows) and find that the probable life of the average survivor would be 119 percent of 28 years equals 33 years. But this pavement is in poorer condition than the average and its traffic is much heavier. Its probable life will be somewhere between 21 (its present age) and 33 (the probable life of the average survivor under average traffic). Taking these limits

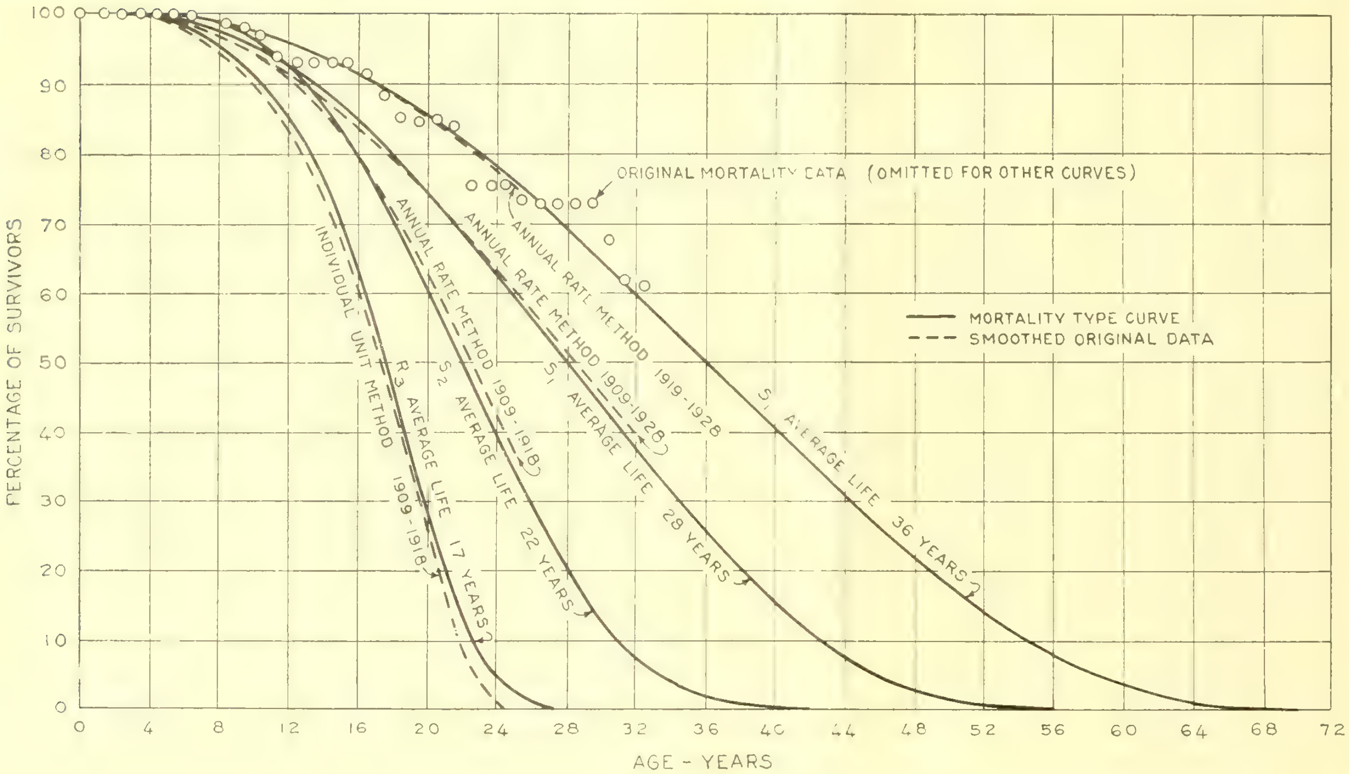

FIGURE 1.—MORTALITY CURVES FOR BRICK-ON-CONCRETE PAVEMENTS, DES MOINES, IOWA, 1909–1928.

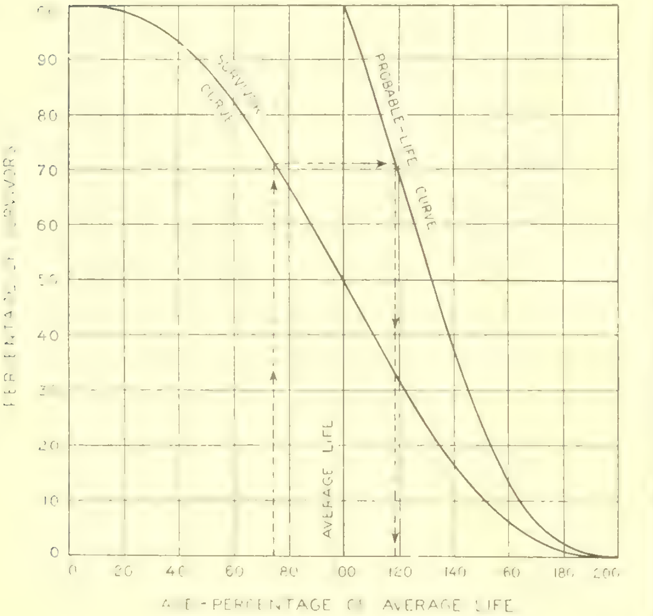

FIGURE 2.—S_1 MORTALITY TYPE CURVE.

and conditions into account, the engineer must forecast its probable life by judgment. It would probably be less than 27 and might be about 25 years.

Case 2.—A brick-on-concrete pavement on a street in a well-to-do residence section. Service age 21 years, as in case 1, but the present physical condition is considerably better than that of the average 21-year-old brick-on-concrete pavements in the city, and the traffic is lighter than the average on such pavements.

As in case 1, the probable life indicated in figure 2 for the average survivor is 33 years; and it may be noted further that only a negligible number of similar pavements have probable lives greater than 170 percent of 28 years equals 41 years. Hence the engineer, using his judgment in view of the actual conditions, would forecast the probable life of this pavement somewhere between 33 and 41 years (quite probably about 35 years).

TABLE 4.—*Numerical data of mortality type curve, S_1*

Age interval, percentage of average life	Renewal during age interval	Surviving at beginning of age interval	Expectancy as a percentage of average life	Probable life, percentage of average life
	Percent	*Percent*	*Percent*	*Percent*
0-10	0.1584	100.0000	100.00	100.00
10-20	.8872	99.8416	90.15	100.15
20-30	2.0108	98.9544	80.91	100.91
30-40	3.3294	96.9436	72.49	102.49
40-50	4.6964	93.6142	64.89	104.89
50-60	5.9971	88.9178	58.05	108.05
60-70	7.1408	82.9207	51.89	111.89
70-80	8.0578	75.7799	46.31	116.31
80-90	8.6971	67.7221	41.22	121.22
90-100	9.0250	59.0250	36.56	126.56
100-110	9.0250	50.0000	32.26	132.26
110-120	8.6971	40.9750	28.26	138.26
120-130	8.0578	32.2779	24.53	144.53
130-140	7.1408	24.2201	21.02	151.02
140-150	5.9971	17.0793	17.72	157.72
150-160	4.6964	11.0822	14.61	164.61
160-170	3.3294	6.3858	11.67	171.67
170-180	2.0108	3.0564	8.94	178.94
180-190	.8872	1.0456	6.52	186.52
190-200	.1584	.1584	5.00	195.00
200-210	--	--	--	200.00

As a further illustration of the possible use of mortality type curves in forecasting the probable lives of particular pavements, it may be said that the author and Mr. W. O. Price of the Iowa State Highway Commission staff are now beginning the preparation of a forecast of the probable amounts of State road pavement reconstruction which will be required from time to time during the next 15 years. Using county maps, on which the date and limits of each pavement construction contract are shown, we are making preliminary personal inspections of all existing primary road pavements, rating them tentatively as to present physical condition. Traffic conditions are to be ascertained by a State-wide traffic survey which is just being started

(Continued on p. 14)

THE RISING ACCIDENT RATE

By WILLIAM G. ELIOT, 3D, Highway Economist, Division of Highway Transport, Bureau of Public Roads [1]

Many Serious Accidents Occur on Wide and Straight Roadways with Lanes Marked. The Present Tendency in Designing 4-Lane Roadways is Toward Separation of Traffic Moving in Opposite Directions by a Center Parkway

STATISTICS of motor vehicle accidents for 1934 indicate that the year's fatalities were approximately 35,500, an increase of 13 percent over 1933. Both in absolute numbers and in percentage of increase, this establishes a new record—of which we are not proud. Not only does humanitarian instinct demand that something be done to check and reverse this trend, but we who are builders and keepers of the Nation's roads have a further personal stake in the matter. If public opinion wakes up in alarm and horror to the situation it may have serious repercussions on the highway engineering profession.

POSSIBLE CAUSES OF INCREASE IN ACCIDENTS CONSIDERED

How are we to account for this distinct upturn in the accident rate? Quite definitely we cannot attribute it to any decline in standards of highway design or maintenance. There are plenty of accidents for which highway defects may be at least partly responsible, but these defects certainly have not increased to cause the large jump in fatalities. Our highways are being built for greater safety every year. Relocations, widening, surfacing, grade separations, and similar projects are constantly correcting hazardous conditions. However, the pace at which these improvements have been provided on our large mileage of road has lagged behind the need for them due to changes in the character of use. Apparently, in spite of all our highway improvements, the margin of safety is actually being reduced by increases in vehicular speeds and volumes, or by other factors over which the highway engineer has no control.

The motor vehicles on the highway are also undergoing constant improvement in design. Lower centers of gravity, technical betterment of brakes, steering gears and tires, safety glass, steel bodies, and increased ease and certainty of control—all may properly be regarded as steps toward greater safety. The speed that goes with high-powered motors is the only important automotive feature that does not seem reconcilable with safety.

The persons who operate motor vehicles make up a large and very representative sample of human nature, and human nature is known to have remained pretty much the same for a long time. Reaction times, acuteness of vision, muscular coordination, and temperament have experienced no sudden change in the past 12 months. The only new factor possibly affecting the vehicle driver is the repeal of liquor prohibition, of which more is said in the following pages.

In seeking an explanation of the rising accident rate, we must also look into the accident "exposure." An increase in the use of motor vehicles, all other circumstances remaining unchanged, would be accompanied by a proportionate increase in accidents. Our best index of vehicle use is gasoline consumption, as revealed in tax data. Preliminary estimates indicate a marked rise in gasoline consumed in 1934 as compared with 1933, but it is not yet possible to determine the extent to which increased travel may account for the increase in accidents.

In this brief summary there are two items that stand out as new factors in the accident situation. One of these is the repeal of prohibition, and the other is the prevailing increase in vehicle speeds.

Repeal has not had all of the dire results that were predicted for it by some of its opponents. Scattered reports, however, do indicate a rise in the number of accidents chargeable, at least in part, to intoxication. Arrests for drunken driving have also increased. Detroit, for example, reports for the first 9 months of 1934 a 96 percent increase in the number of drinking

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[1] Paper presented before the twenty-seventh annual meeting of the Mississippi Valley Conference of State Highway Departments, Chicago, Ill., Feb. 1, 1935

Highway Accidents Are Increasing in Number in Spite of Improved Road Conditions. It Is Evident That Effective Measures Must be Taken to Reduce the Loss of Life and Number of Injuries.

motorists involved in traffic accidents, and a 78 percent increase in motor vehicle injury accidents involving drinking drivers.[2]

There is no question that intoxicated drivers and intoxicated pedestrians must be kept off the roads. While the obvious answer is the strictest enforcement of existing laws against intoxicated driving, the practical difficulty is to determine when a man is actually, or legally, "under the influence." Research is now under way, both in this country and abroad, to develop simple physiological tests, based on alcohol concentration in certain body fluids, but it is too early to predict possible results. Such tests must be absolutely reliable or they will be worse than useless. There appears to be no way to detect the man who is not drunk, but who has had just enough to impair the faculties needed by a safe driver, until he has had an accident or violated some traffic regulation. Then, perhaps, we can prevent a repetition by depriving him of his driver's license, or by other suitable discipline.

INCREASED SPEED AN IMPORTANT FACTOR

The second new factor in the accident problem is the increasing speed for which cars are now being designed. Within the last 2 or 3 years, the lowest-priced cars have been designed for performance almost equal to that of the most expensive ones. The maximum brake horsepowers of the 1930 models of three of the most popular low-priced cars were 40, 46, and 45, respectively. For the 1933 models the corresponding figures were 65, 65, and 70, and for the 1934 models 92, 80, and 77 horsepower, respectively. This development in the cars that make up so large a proportion of automobile sales has had a controlling effect on the general average. Anyone who buys a car now can travel at speeds reserved only a few years ago for a select few.

Raising or removal of legal speed limits in recent years reflects changing driving habits, but in no way measures the change. In fact, we have very few data as to average highway speeds until very recently, though our personal experience testifies that they have been markedly stepped up. As far back as 1925 the State of Rhode Island began making stop-watch speed observations which have been carried on more or less continuously since. The earlier records show an average speed (for uninterrupted travel) of 25.6 miles per hour. Incomplete analysis of studies made by the Bureau of Public Roads on a number of highways in eastern Massachusetts during the past summer indicates an average speed of only about 33 miles per hour on those roads. At one point well away from any settled community an average of 39 miles was observed for vehicles of all classes. The figures seem surprisingly low. We are accustomed to think of travel at speeds consistently over 40 or even 50 miles per hour, yet observations in a number of States have rarely shown averages exceeding 40 miles. It is likely that in States where travel distances are greater and where there are fewer settled areas to prevent a building up of speed the averages will run somewhat, but not a great deal, higher.

From the safety standpoint the average speed tells only a part of the story. The danger in the rising average is in the increase of speed at the upper end of the scale. There are always some drivers who try to take full advantage of the top speeds of which their cars are capable, and many who are not happy except when they are in a hurry to get somewhere. Generally speaking, it is these higher speeds that cause trouble, not only in themselves, but also because any lower speeds deceptively seem safe. One of the problems of small-town traffic regulation is that drivers coming in from the open highway fail to reduce speed to a safe degree. Thirty or 35 miles per hour seems like crawling after many miles at 60 or better.

Warning Signs and Road-Marking Are Important Factors in Accident Prevention. Conspicuous Progress Has Been Made in Standardizing and Placing Signs and Markings.

We have too long evaded the issue by such sophistry as the familiar assertion that "Speed in itself is not a cause of accidents." Eighty miles per hour in the right place is safer, we have argued, than 20 miles under unfavorable circumstances. True, but it gets us nowhere. By the same method of argument, we can easily prove that any other dangerous condition is not "in itself" a cause of accidents. Speed is a cause of accidents, and we might as well admit it frankly.

The present generation demands fast travel even at its high cost in life, limb, and property. We cannot, of course, arbitrarily reduce all speed to a safe pace for all, regardless of differing highway conditions and differing abilities of operators. For the most part we can only continue along present lines, with redoubled effort toward safety.

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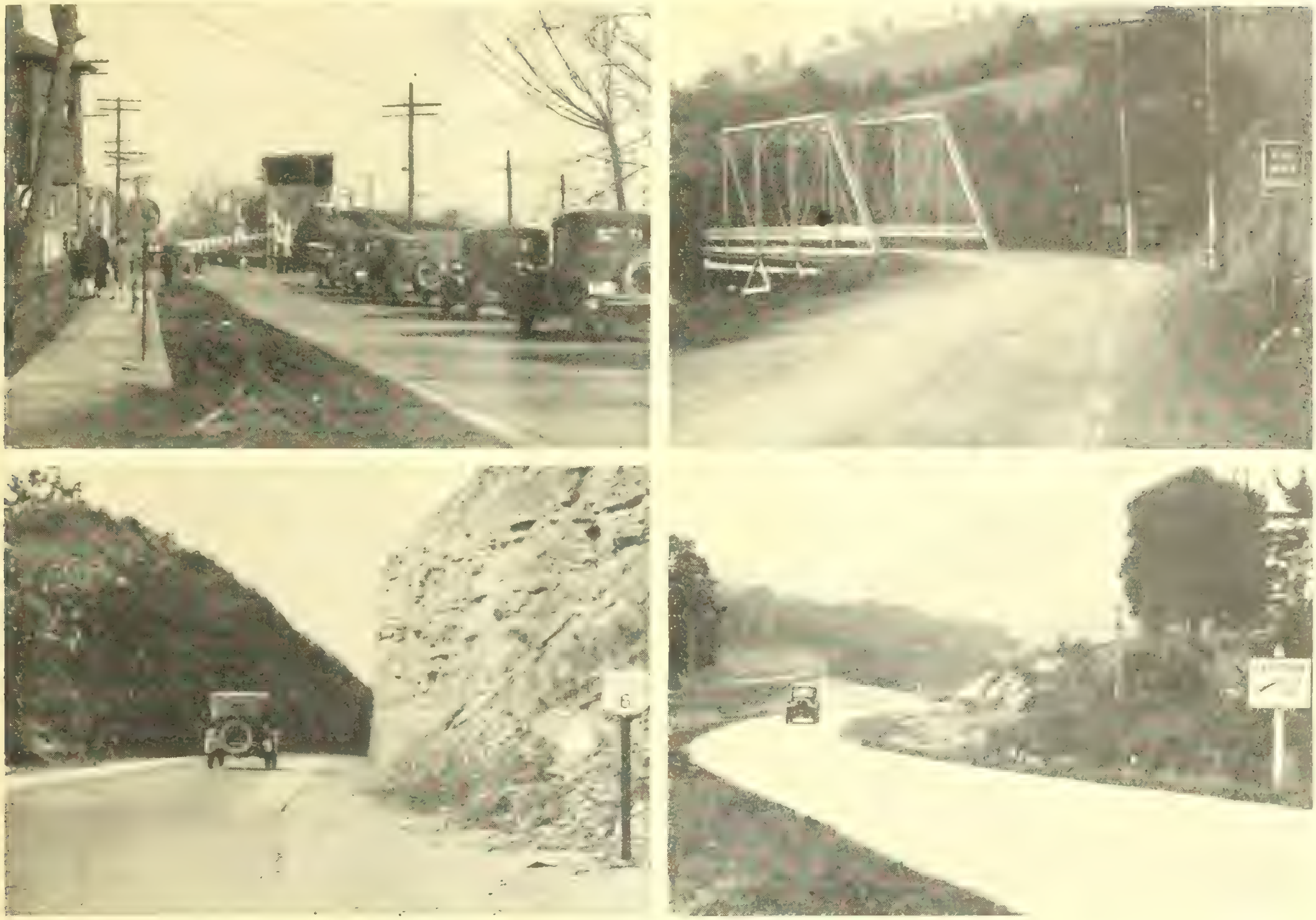
[2] Public Safety, December 1934, p. 18.



The Increased Speed and Volume of Traffic Have Made Necessary a Large Amount of Work in Further Improving Existing Surfaces. Grade Crossings Need to be Eliminated, Bridges Widened, Sight Distances Increased, and Narrow Surfaces Widened.

SAFER HIGHWAYS AND CHECKS ON EXCESSIVE SPEED NEEDED TO REDUCE ACCIDENTS

In the first place, we shall have to go on improving road design and eliminating danger points. This needs no discussion in a gathering of highway engineers. The difficulty is not a lack of knowledge of how we should do it. It is the impossibility of finding within any reasonable time the almost unlimited funds that would be needed for a really satisfactory program of highway improvement. Divided highways and grade separations, essential for the safe movement of traffic in congested areas, and desirable for safety everywhere, must be adopted more generally as funds can be made available. Adequate highway lighting is being urged for safety, but satisfactory standards have not yet been agreed upon, and its cost would probably prevent any widespread program of rural lighting. Wide shoulders for parking and footpaths for pedestrians will prevent many accidents and are relatively inexpensive as compared with most safety features.

Improvement of sight distances, necessary for the safety of high-speed travel, can often be accomplished at small cost by the reduction of horizontal or vertical curvature.

For the assistance of the motorist in recognizing hazardous conditions, adequate signs and markers are of great importance. The latest word on this subject can be found in the newly revised manual recently produced by a joint committee of the American Association of State Highway Officials and the National Conference on Street and Highway Safety.

Traffic signals for the orderly control of traffic are also part of the safety program, where traffic is heavy and grade separation is not practicable.

So much for what the highway engineer as such can do. He does not and cannot assume the entire responsibility for safety. It would be very pleasant if we could design and build our highways so that traffic would be wholly self-regulating, but that is asking too much. Some curb on dangerous driving is necessary by legal regulation.

In checking excessive speed by regulation, there are three courses open—a definite speed-limit law, a redesigning of motor vehicles for lower top speeds (by means of governors or by a more fundamental motor change), or a much stricter selection of motor vehicle operators on the basis of their ability to handle cars safely and at properly controlled speeds.

The speed-limit law here referred to would be aimed only at the higher speeds and would be absolute, not "prima facie". It would be justified on grounds similar to those on which we now defend the limiting of vehicle sizes and weights. In proposing uniform maximum dimensions and gross loads, we are setting up a standard to which our roads shall be built. If we concede the right to limit sizes and weights in the interests of safety and economy of design, we must recognize also the logic of restricting speed to a maximum which can reasonably be provided for in the design. Traffic that must move at a faster pace should be diverted to rail or air. What should this legal speed be? I do not know. Even if it were set no higher than 60 miles per hour it would cause possible annoyance to only a relatively small proportion of the drivers on the road. Studies on Maryland highways, reported at the 1933 meeting of the highway research board by Dean A. N. Johnson of the University of Maryland, showed only 2 percent of the observed vehicles traveling in excess of 55 miles per hour on open highways where the general speed limit of 40 miles applied.

Regulating the mechanical design of vehicles so that none would be capable of exceeding a reasonable speed would have the same shortcoming as the imposition of a highway speed limit; namely, that it would affect only top speeds. In order not to be an intolerable inconvenience, it would have to set the limit at a speed exceedingly dangerous for any but very favorable circumstances. Unless the limit on top speed could be achieved without sacrific of acceleration and power, it would be most unpopular with American drivers, who expect "snappy" performance. It is doubtful if this proposal would find any considerable public support, therefore—at least not until we are ready to think more of economy of operation than of acceleration and speed. The enormous price we are paying for "performance" is to be measured in terms of excess horsepower, inefficient load factor, rapid mechanical depreciation, and, of course, accidents.

Enforcement of Highway Regulations Is a Necessary Step in Accident Control.

LICENSING DRIVERS AN EFFECTIVE SAFETY MEASURE

In the end, the safe use of motor vehicles depends mostly upon the operator himself. No law or regulation can determine in advance what speed is "too fast for conditions" in every situation that may arise. A safe driver is one whose alertness and judgment can be depended upon to keep him from traveling in excess of a safe speed.

The reckless or otherwise incompetent driver can be disciplined, instructed, or eliminated through two agencies—a State highway police and an adequate system of licensing drivers. The presence of uniformed motorcycle police on a highway is a powerful influence for good driving, and incidentally, but frequently, a great help to motorists in trouble. Licensing of drivers provides an opportunity for testing their capabilities as drivers and their knowledge of motor vehicle regulations before they are permitted to use the public highways. Even more important, perhaps, is the power reserved by the State to suspend or revoke these licenses for cause. Driver's license examinations do not now, and perhaps never can, reveal all of the hidden flaws of recklessness, slow muscular or nervous coordination, indulgence in intoxicants, and the like. However, just as soon as a licensed driver begins to develop a bad record, either in accidents or law violations, the State can bring him promptly to account by depriving him of his right to drive. Often a hearing and a warning are sufficient.

The value of a license law is effectively demonstrated by an analysis recently published by the National Safety Council. The States were classed according to whether they had a standard license law and administration, a substandard license law and/or administration, and those having no license law, the last class being subdivided into several groups of neighboring States.

> From 1926 to 1933 the motor vehicle death rate (per 10,000,000 gallons of gasoline consumed) in standard license law States dropped 25 percent, while the rate in other States increased 14 percent. * * * In the seven States with substandard law and/or administration the death rate in 1933 was 7 percent above 1926. Among seven midwestern nonlicense States there was an advance of 12 percent. In 10 southern nonlicense States the rate rose 26 percent. For five western nonlicense States there was an increase of 15 percent.[3]

Act II of the Uniform Vehicle Code drafted by the National Conference on Street and Highway Safety is a model, standard license law, tested by wide experience, and ready for adoption by any State. As a safety measure, no single piece of legislation, adequately administered, seems more likely to accomplish its purpose.

STUDY OF ACCIDENT CAUSES NECESSARY FOR PROPER CORRECTIVE MEASURES

So much for the specific attack on some of the more urgent elements of the accident problem. To the extent that we can make the highway, by proper design, safe for reasonable speed; to the extent that we can enforce that speed; and to the extent that we can weed out the unfit driver, we shall achieve safer highways.

These remarks have therefore been directed toward a general safety program, though emphasizing only the recent developments in the accident situation. Some of the statements made here have been rather broad and over-simplified. As a matter of fact, we still have much to learn about accidents, and especially why they are happening in any particular State or locality. Since accident prevention must be achieved one step at a time, the more we know about detailed causes, the more intelligently we can go about organizing our campaign and selecting our immediate objectives. For every accident we should know exactly where it occurred, who was involved, and what conditions contributed to it.

A report of every motor-vehicle accident involving personal injury or serious property damage should be required by law, to be made to the nearest police agency or directly to the State authorities. For uniform and complete reporting it is essential that a standard form be used. Even an experienced observer will omit significant details unless he has an outline to guide him. The form adopted by the National Safety Council is recommended for its completeness and its simplicity.

Public Safety, August 1934.

Little Progress Has Been Made in Constructing Footpaths in Spite of the Obvious Need for Them in Many Locations. The Death Toll of Pedestrians Is Large and Bridges Are Particularly Dangerous.

A Method of Increasing Sight Distance on Sharp Curves. In This Case Conditions Are Improved but Are Still Dangerous.

From an adequate record of place of occurrence, we can discover the "sore" spots in our highway systems, and after careful analysis of the accident data and diagnosis of the trouble, we can prescribe the remedy. From our record of motor-vehicle operators involved in accidents, we may hope to remove "accident-prone" drivers from the road. From the circumstances most frequently attending these accidents, law enforcement agencies and highway administrators may plan their campaigns against special hazards wherever found.

As a means of concentrating public attention upon these matters, it is suggested that a governor's commission be appointed in each State, empowered to inquire into the extent and causes of highway accidents. Full publicity should be given to its studies, and any weakness in existing accident records or law enforcement should be brought to light. Causes of accidents as revealed by its findings should be stressed by the press in an educational campaign for better and safer driving. Withput public opinion behind us, we cannot progress far, since safety costs money on the one hand, and, on the other, demands a certain surrender of personal liberty. With an aroused public sentiment for safety, however, the driver who causes accidents becomes an offender against the State, not merely an unfortunate victim of circumstance.

(Continued from p. 2)

development of a coherent plan sufficiently broad to encompass the major needs here touched upon is one of the prime essentials of the immediate operations of each State highway department. In the absence of existing authority on the part of the State highway departments to undertake such planning, I have urged that legislative sanction be sought. The Federal highway legislation has already recognized the benefits to be obtained through studies and has provided for Federal cooperation in them.

Studies of this sort cannot be of a perfunctory nature. They must contemplate the formulation of a comprehensive plan for the development of a fully adequate highway transportation system consistent with modern economic and social trends. The facts obtained must be sufficient to indicate the relative importance of both rural and urban roads which for economic or social reasons may be considered eligible for inclusion in the improvement program. The special problem of approaches to cities and the connections through and around them needs the attention necessary to plan such improvements in anticipation of their undertaking.

An inventory of the entire existing highway plant is imperatively needed, and a careful estimate of the financial provision necessary for its preservation, renewal, and progressive development should be made. This extends to all major parts such as the examination and rating of the condition and capacity of bridges and the fixing of priority for the elimination of existing grade crossings of railroads in which we should, of course, seek the opinions and plans of railroad managements.

The final object should be the conception and formulation of a composite plan for the development of all highways, regardless of their present legal classification or condition, and an estimate of the probable cost. The study also should indicate the benefits which are to be realized from such improvements, considering the direct users, the landowners, and others who benefit indirectly. On the basis of such information, intelligently consolidated, there need be no hesitation in undertaking the broadened highway program with faith that the growth of population, the promotion of the safety and economy of highway transportation and the enlarged social and recreational benefits to be secured, will justify and maintain the cost if the plan is laid with intelligence and faith in the future.

REGULATION OF OUTDOOR ADVERTISING UPHELD IN MASSACHUSETTS COURT DECISION

THE AUTHORITY of the Massachusetts Department of Public Works to regulate outdoor advertising on public highways and the Federal constitutionality of the act under which regulation has been attempted have been sustained in a decision of the Supreme Judicial Court of Massachusetts in an opinion filed January 10, 1935. The following statements are based on the printed opinion.[1]

The constitution of Massachusetts was amended on November 5, 1918, in these words: "Advertising on public ways, in public places, and on private property within public view may be regulated and restricted by law." Following this constitutional amendment legislation was enacted requiring the State department of public works to make "rules and regulations for the proper control and restriction of billboards, signs, and other advertising devices * * * on private property within public view of any highway, public park, or reservation", with an exception not material to this review. The legislation further provides that such rules and regulations may require that the billboards, signs, and other devices be licensed and that fees be prescribed. The department of public works has power to amend or repeal regulations.

Cities and towns may further regulate and restrict billboards and other devices within their respective limits by ordinances or by laws not inconsistent with State regulation or laws.

REGULATIONS DESIGNED TO PROTECT NATURAL BEAUTY AND SAFETY OF TRAVEL

The rules and regulations now in force were adopted by the department of public works to be in effect on and after January 24, 1924.

The substance of those rules and regulations is as follows: Provision is made requiring all those engaged in outdoor advertising to be licensed by the department of public works, such licenses to be in force for 1 year unless sooner revoked. The fee for such license and for renewal thereof is $50. No one may engage in the business of outdoor advertising without permits for each advertising device for which two annual fees of $2 each are exacted, one for examination and the other for inspection, subject to various regulations as to details, and to revocation for cause.

Provision is made for advertising devices within public view from any highway, public park, or reservation by persons not engaged in the business of outdoor advertising. In general, outdoor advertising within any public way is forbidden. "No permits will be issued for outdoor advertising in any location which is within 300 feet of any public park or reservation, if within view of any portion of the same" with an exception not here material, and permits may be granted for the location of electrical display signs on buildings under such restrictions as the department of public works may impose. "No outdoor advertising shall be painted or affixed upon any fence or pole within 50 feet of any public way nor directly on the wall of any building."

Dimensions and material of all outdoor advertising devices may be prescribed by the department of public works, and objectionable matter may be required to be removed. No renewal permit will be granted for advertising devices unless the front, back, braces, anchors, and lattice work thereof are painted and kept in proper condition. Advertising devices and the ground about them must be kept free from all rubbish or any materials objectionable in the opinion of the department of public works.

Section 6 of the regulations is entitled "Restrictions" and is in these words: "A. No permit will be granted for the location or maintenance of billboards, signs or other advertising devices near certain public ways where, in the opinion of the division, having regard to the health and safety of the public, the danger of fire, and the unusual scenic beauty of the territory, signs would be particularly harmful to the public welfare. B. No permit will be granted for the location, erection or maintenance of any billboard, sign or other advertising device within a radius of 150 feet from the point where the center lines of two or more public ways intersect. This provision shall not apply to districts which the division may determine are of a business character. C. No billboard, sign or other advertising device shall be erected, displayed or mantained in any block in which one-half of the buildings on both sides of the street are used exclusively for residential purposes, except that if the written consent of the owners of a majority of the frontage on both sides of the street in such block is obtained and is attached to the application for a permit to erect, display or maintain such billboard, sign or other advertising device the division may permit the erection, display or maintenance of the same. D. No permit will be granted for the erection or maintenance of any billboard, sign or other advertising device if said billboard, sign or advertising device is to be located: (1) Nearer than 50 feet to the boundary line of any public way; (2) Nearer than 100 feet to the boundary line of any public way, if within view of any portion of the same, if said billboard, sign or other advertising device exceeds an area of 32 square feet; (3) Nearer than 300 feet to the boundary line of any public way, if within view of any portion of the same, if said billboard, sign or other advertising device exceeds a length of 25 feet or a height of 12 feet; (4) In any event if said billboard, sign or other advertising device exceeds a length of 50 feet or a height of 12 feet; except that the division may permit the erection of billboards, signs or other advertising devices which do not exceed 40 feet in length and 15 feet in height if not nearer than 300 feet to the boundary line of any public way. Provided, however, that this paragraph shall not apply to districts which the division may determine are of a business character. E. No permit shall be granted for the erection of a billboard, sign or other advertising device which will, in the judgment of the division, obstruct the visibility of another sign. F. No billboards, signs or other advertising devices shall be located nearer to other billboards, signs or other advertising devices than 50 feet, unless said billboards, signs or other advertising devices are placed back to back. Provided, however, that this provision shall not apply to districts which the division may determine are of a business character."

Section 7 of the regulations required that all advertising devices whether erected before the adoption of the rules and regulations or not should be removed by

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[1] Published by Wright & Potter Printing Co., 32 Derne Street, Boston.

July 1, 1925, provided that extension might be granted to not later than July 1, 1927, unless maintained under a permit issued in accordance with the regulations.

A form of ordinance or bylaw was set forth, which, if adopted by a city or town, would be approved by the department of public works. Such a bylaw was adopted by the town of Concord.

COURT DECISION BASED ON HEARINGS AND THOROUGH STUDY

Fifteen suits in equity were brought by individuals, firms, and corporations engaged in outdoor advertising as plaintiffs; 14 suits were against the commissioners of the department of public works as defendants, and 1 suit was against the officers of the town of Concord. The object of the suits was to obtain decrees to the effect that all and certain parts of the rules and regulations adopted by the department of public works and the bylaw adopted by the town of Concord are void, unconstitutional, and of no effect.

Pending the final disposition of the suits an injunction was issued against the disturbance of signs, billboards, and other advertising devices of the plaintiffs.

The cases were consolidated into a single cause for hearing and were referred to a master under a rule "to hear the parties and their evidence, and to report his findings * * * together with such facts and questions of law and portions of the testimony as any party may in writing request." The master heard the parties and their evidence on 114 days and took a view of signs, billboards, and advertising devices in different sections of the Commonwealth, traveling approximately 1,000 miles with counsel for that purpose. The record consists of five large printed volumes. The master filed a comprehensive report comprising many hundreds of printed pages. The plaintiffs filed 78 numbered objections. After receipt of the copy of a draft of the master's report, the plaintiffs filed a large number of requests for report of facts, questions of law, and portions of testimony, covering about 22 pages of the record. They then filed a motion that the report be recommitted to the master. It contained many divisions, referred to divers of their objections, and requested a report of evidence concerning numerous findings, and of rulings. The motion was accompanied by a considerable number of requests for rulings of law.

Decree was entered that this motion to recommit be "granted as matter of discretion, without ruling upon any question of law." Pursuant to this decree further hearings were held by the master and a supplemental report filed. The plaintiffs filed objections filling approximately 240 pages of the record. They filed a second motion to recommit the case to the master, together with many requests for rulings. From an interlocutory decree denying this motion as a matter of discretion without any rulings of law, the plaintiffs appealed. The defendants moved to confirm the master's reports and to enter final decrees and the case was reserved for determination by the full court.

The master found that the estimated market value as of January 1, 1924, of the combined plants of the plaintiffs, including outdoor advertising devices, interests in land, structures, equipment, and shops was $5,000,000. Full compliance with the rules and regulations promulgated would have required the removal or relocation of 75 to 90 percent of the outdoor advertising signs then existing in the State.

REGULATIONS FOUND TO BE A JUSTIFIABLE USE OF POLICE POWER

The opinion of the Supreme Judicial Court of Massachusetts in which it is held that the plaintiffs are not entitled to relief, discusses the various points at issue at some length.

The constitutional right asserted by the plaintiffs to conduct outdoor advertising without interference by the enforcement of rules and regulations was denied. The only real value of a sign or billboard lies in its proximity to the public thoroughfare within public view. The object of outdoor advertising in the nature of things is to proclaim to those who travel on highways that which is on the advertising. It does not appeal alone to the desire or consent of such persons; it is forcibly thrust upon the attention of all such persons, whether willing or averse. For those who strongly wish to avoid advertising there is no escape; they cannot enjoy their natural and ordinary rights to proceed unmolested. It is illusory to suggest that a traveler may close his eyes and mind to the advertising matter displayed. One cannot well travel upon the highway with any enjoyment or with safety to himself or others with his eyes shut.

The rules and regulations as promulgated, although they operate as a severe limitation upon the business of the planitiffs, are found to be justified as a police measure for protection of travel. Advertising devices on private land manifestly are designed to attract the attention of motorists. The opinion of the executive head of the department of public works that billboards have a distractive effect upon the drivers of automobiles and that they constitute traffic hazards except in business sections was considered as entitled to weight. The danger arising from the operation of automobiles is very great. The toll of life and suffering of human beings exacted by this cause is appalling. Rules and regulations of advertising devices, even to the extent of prohibition, having a reasonable tendency to prevent obstructions to traffic or to facilitate safety of travel are permissible.

Another basis for the rules and regulations is that they tend to protect travelers from the intrusion of the public announcements thrust before their eyes by signs and billboards. The people of the State by the adoption of the constitutional amendment and subsequent legislation have declared that signs and billboards within public view may be regulated and restricted. One permissible and reasonable ground for such regulation is that travelers may be free from annoyance. This is not a mere matter of banishing that which in appearance may be disagreeable to some. It is protection against intrusion by foisting words and emblems of signs and billboards upon the mass of the public against their desire. To adjust the conflicting interests of the public and of the individual is a proper legislative function.

PRESERVATION OF SCENIC BEAUTY SUFFICIENT BASIS FOR REGULATION

It was urged by the plaintiffs that the rules and regulations, so far as they relate to the preservation of scenic beauty and the exercise of taste and fitness in the location of billboards, are void because they rest on aesthetic considerations. Massachusetts decisions were cited in which it was held "that aesthetic considerations alone or as the main end do not afford sufficient foundation for imposing limitations upon the use of property under the police power." The phrase "aesthetic considerations", in the opinion of the court has commonly been applied to regulations as to the character, form and appearance of constructions to be erected. The rules and regulations in question have a different aim. They are designed to promote safety of travel, to shield travelers from the unwelcome obtrusion of business appeals, to protect property from depreciation and to make the commonwealth attractive to visitors from other States. Grandeur and beauty of scenery contribute highly important factors to the public welfare of a State. To preserve such landscape from defacement promotes the public welfare and is a public purpose. It is held that "Even if the rules and regulations of billboards and other advertising devices did not rest upon the safety of public travel and the promotion of the comfort of travelers by exclusion of undesired intrusion, we think that the preservation of scenic beauty and places of historical interest would be a sufficient support for them. Considerations of taste and fitness may be a proper basis for action in granting and in denying permits for locations for advertising devices."

REGULATION DOES NOT VIOLATE CONSTITUTIONAL RIGHTS

With regard to the contention that the rules and regulations prohibit rather than regulate the business of outdoor advertising the court says:

> If, however, it be assumed in favor of the plaintiffs that their business on the lines heretofore conducted will not be profitable when conducted in conformity to the regulations, that does not, in all the conditions disclosed, entitle them to relief. The practical operation and effect of a statute, bylaw, or ordinance is sometimes an important factor in determining its constitutionality. * * * The scope of that principle, however, is much narrowed when the subject matter is indubitably within legislative competency. The power to regulate outdoor advertising on private land within public view is established by article 50. The circumstance that the practical effect of the regulations may render the business as heretofore conducted by the plaintiffs unprofitable does not brand the regulations as invalid.

It was contended by the plaintiffs that the rules and regulations as interpreted and applied violated the rights guaranteed by the fourteenth amendment to the Constitution of the United States in that they are deprived of their property without due process of law and are denied the equal protection of the laws. In expressing the opinion that this contention cannot be sustained the court says:

> It must, in our opinion be regarded as settled by these decisions of the Supreme Court of the United States that billboard and like advertising devices upon private property have such demonstrated potentialities for harm to the general welfare that they may be prohibited in certain localities by public authority. The principle has become so thoroughly established that billboards are mentioned as illustrations of an appropriate subject for regulation and restriction. Advertising devices such as those of the plaintiffs relate to the promotion of trade and commerce. The exclusion of them from regions of natural scenic beauty and historic interest does not exceed the reasonable bounds of the police power. The circumstance that in the cases at bar there have been few instances where billboards have been used to the public harm by the evil-minded is not decisive.

(Continued from p. 6)

cooperatively by the Iowa State Commission and the Iowa Federal Emergency Relief Administration. We expect to have the assistance of the best judgment of the commission's own district and other engineers and to use mortality type curves, about as explained above, to aid in applying their judgments and our own.

INVESTIGATION OF THE ACTUAL SERVICE LIVES OF RURAL HIGHWAY PAVEMENTS INAUGURATED

The author is much gratified to be able to announce the immediate start of active work in a cooperative project of the United States Bureau of Public Roads and the Iowa Engineering Experiment Station for the collection, study and publication of extensive data of the actual service lives of rural highway surfaces of various types in several States. It was the original plan that this should be a joint project of the United States Bureau of Public Roads and the Highway Research Board. Some technical difficulties have made the other set-up necessary, but the director of the board has promised his active assistance and the subcommittee on pavement mortality of the board's committee on transportation economics will be asked to participate actively in planning and guiding the work. Cooperation is sought from highway commission and other highway officials and engineers in the several States.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF FEBRUARY 28, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 5,595,178	$ 3,029,941	$ 35,889	304.6	$ 2,354,828	$ 841,326	$ 828,175	140.1		$ 422,187	19.1	$ 76,485	$ 843,669
Arizona	3,878,555	1,338,712	4,352,582	3,697,024	55,699	291.0	1,023,303	162,379	821,290	70.8	$ 1,057	330,385	28.8	18,094	130,838
Arkansas	3,334,167	1,714,000	3,004,272	2,393,539	137,100	154.9	1,851,377	798,211	787,910	73.8	39,563	212,948	5.6	102,854	576,041
California	7,912,928	3,713,643	9,109,588	6,830,077		277.2	3,801,118	1,076,204	1,471,100	72.7		929,490	65.8	6,547	1,313,053
Colorado	3,437,265	2,424,504	3,889,817	3,366,958	440,498	181.0	1,888,170	60,627	1,692,148	90.2	9,680	291,858	11.4		
Connecticut	1,404,213	607,500	797,613	795,279		14.5	1,324,901	608,934	453,399	21.7		154,100	1.8		1
Delaware	892,544	461,697	910,189	869,662	36,177	38.2	429,141		413,964	10.7	8,734			14,149	11,557
Florida	2,513,011	1,116,600	1,986,534	2,180,563		108.9	1,066,981	264,471	734,958	42.4		55,579	.4	73,977	326,063
Georgia	5,045,532	2,566,745	3,640,506	3,447,388		252.7	2,127,680	1,393,826	698,854	98.9	41,770	990,756	61.4	162,608	867,135
Idaho	2,166,858	1,131,910	2,143,015	1,974,315	97,326	184.1	543,662	171,151	360,316	30.0	21,392	162,097	17.7		512,171
Illinois	4,442,467	3,060,041	1,994,740	1,958,990	19,269	38.5	3,010,696	2,421,646	589,050	34.6	36,045	1,064,927	21.7	25,787	1,386,794
Indiana	5,018,921	2,843,478	3,250,269	3,222,226		107.2	1,806,095	1,691,931	113,453	40.4	58,760	1,980,538	126.9	46,004	749,487
Iowa	5,027,830	2,717,361	4,819,401	4,601,240	54,420	288.6	1,820,178	380,600	1,342,273	111.8	9,800	507,064	24.7	36,190	313,604
Kansas	5,044,802	2,354,131	5,310,444	4,931,898	171,368	542.7	1,602,827	56,400	1,546,427	165.9		636,336	46.3	56,504	
Kentucky	3,751,605	1,527,324	3,622,609	3,353,251	33,571	243.9	642,576	289,920	300,503	50.6	94,476	501,843	47.1	13,958	691,406
Louisiana	2,711,152	1,380,419	1,756,275	1,752,495		73.9	1,891,991	905,474	472,715	12.6	45,353	698,353	19.5	7,830	209,351
Maine	1,517,660	793,644	1,361,991	1,326,424		43.7	802,573	239,455	563,118	13.5	12,524	197,402	6.8	39,157	33,124
Maryland	1,782,263	289,609	791,624	778,132	3,843	15.1	886,878	771,460	115,418	20.0	39,135	97,729	1.7	193,536	72,620
Massachusetts	1,101,716	1,632,874	1,409,030	1,016,079		37.4	562,032	52,687	457,524	9.2		552,128	10.1	32,950	623,222
Michigan	6,051,532	3,226,284	4,790,228	4,693,839		223.4	2,742,825	1,348,200	1,379,825	101.8		1,627,975	69.9	9,494	218,484
Minnesota	4,561,011	2,642,244	5,637,753	4,344,165	1,192,164	864.7	924,069	179,056	686,213	130.1		576,987	69.9	37,789	186,379
Mississippi	3,489,337	2,301,148	4,346,833	2,332,709	87,605	224.1	2,108,174	974,048	339,905	116.9	32,821	1,050,906	54.6	149,759	822,732
Missouri	5,237,532	2,132,426	4,660,917	4,126,069		187.9	2,439,372	1,065,079	1,203,173	70.4		726,674	24.2	46,385	202,579
Montana	4,463,849	2,714,208	5,493,149	4,459,720	466,873	426.3	1,752,771	4,129	1,679,685	170.3		309,616	34.2		258,034
Nebraska	3,914,481	1,982,182	5,141,415	3,892,837	54,009	373.4	1,560,207	21,644	1,192,183	75.4		692,946	32.5		43,044
Nevada	2,909,367	1,350,356	2,833,939	2,704,502	76,039	268.7	750,483	108,771	641,712	100.9	17,734	14,755	2.6	78,379	617,850
New Hampshire	692,119	484,731	638,684	612,389		10.8	425,572	79,730	324,780	11.2		116,767	1.3		43,185
New Jersey	3,173,019	951,379	1,711,231	1,691,699		31.6	1,686,118	1,472,042	24,919	16.7		332,908	3.5	9,279	593,552
New Mexico	2,846,648	1,676,769	3,033,052	2,760,948	128,175	297.5	1,258,400	85,700	1,101,806	96.6					446,788
New York	10,465,672	3,748,600	10,173,868	8,394,638	53,000	210.3	7,632,928	2,010,070	2,391,600	134.8		923,820	11.7	60,965	375,180
North Carolina	4,761,147	2,040,068	4,637,100	3,584,367	209,578	581.6	1,278,683	604,315	403,141	136.0	249,644	132,465	31.8	322,821	1,294,884
North Dakota	2,902,224	1,469,484	3,129,885	2,645,348	58,556	1,023.9	366,775	52,853	239,860	133.0	47,825	550,401	285.7	156,199	620,666
Ohio	7,277,758	3,539,256	7,474,205	7,059,927		192.4	1,935,620		1,698,610	45.4		1,345,575	22.9	217,831	495,070
Oklahoma	4,618,399	2,342,590	3,815,675	3,714,071	14,570	278.4	2,317,780	885,837	1,310,267	98.4		497,898	21.2	8,492	519,855
Oregon	3,053,448	1,452,741	3,339,481	3,039,829	8,928	183.0	1,143,245	13,619	1,072,626	50.4		214,490	9.8		156,698
Pennsylvania	6,691,194	4,554,082	5,802,997	5,504,616	98,425	123.1	4,077,450	1,098,013	2,766,261	68.7	865	1,507,768	29.2	87,699	181,627
Rhode Island	974,367	464,572	968,005	899,627		20.5	542,465	46,205	414,131	13.6		25,194	.7	33,535	25,248
South Carolina	2,729,583	1,385,477	2,200,772	2,180,097		194.1	929,956	427,424	462,879	75.2	20,920	778		101,142	921,820
South Dakota	3,005,739	1,523,821	2,763,620	2,246,737	34,870	454.9	696,181	564,746	119,781	173.4	137,949	891,604	145.8	56,307	477,567
Tennessee	4,246,309	2,105,453	4,428,459	3,741,850	64,152	175.2	1,021,521	411,795	513,324	33.1	56,807	737,471	24.9	35,856	790,507
Texas	11,588,643	6,858,253	11,328,976	10,835,799		981.4	3,614,322	724,808	2,849,863	283.4	17,681	1,506,940	124.2	10,355	2,501,460
Utah	2,367,205	1,066,345	2,762,634	2,279,074	365,500	237.8	791,275	84,632	496,100	61.6		8,000	.2	3,499	196,745
Vermont	928,184	466,042	970,709	909,613	28,464	47.9	277,219	10,670	249,114	13.9		142,265	5.3	7,901	46,199
Virginia	3,708,379	1,882,693	3,556,591	3,324,966	18,172	151.2	1,282,297	76,416	1,121,250	48.3	130,485	445,811	33.6	176,512	297,461
Washington	3,057,934	1,553,206	2,771,879	2,556,090	196,077	99.4	1,603,419	434,930	1,007,442	27.6	30,664	82,427	2.8	36,250	267,260
West Virginia	2,013,405	1,140,167	1,947,430	1,875,902	60,892	71.2	554,218	111,669	425,657	20.0		284,743	9.2	25,834	368,875
Wisconsin	4,697,518	1,865,947	4,437,423	4,316,380	3,324	213.1	802,396	239,441	462,624	42.8	134,828	785,901	37.5	6,868	614,098
Wyoming	2,250,663	1,692,907	2,310,490	2,035,483	85,400	476.8	1,231,302	209,202	995,932	144.1		448,728	92.2	5,977	162,847
[illegible] Hawaii	1,683,956	598,778	349,204	250,764		12.4	1,826,261	1,428,169		27.2				5,023	598,778
TOTALS	[illegible]	94,506,322	178,207,281	154,539,536	4,389,933	11,835.1	79,060,311	26,959,915	41,337,258	3,631.1	1,296,512	25,773,033	1,698.[illegible]	2,596,881	23,006,098

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2 - PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF FEBRUARY 28, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 1,389,928	$ 1,264,961	$ 1,322,462	$ 1,322,463		35.3	$ 1,035,694	$ 920,479	$ 115,215	31.9		$ 137,191	2.3	$ 146,987	$ 812,555
Arizona	807,482	305,191	629,936	619,479	$ 8,996	12.3	59,340	20,500	28,309	1.6	$ 129,322		.2	38,682	267,886
Arkansas	1,904,534	857,025	1,538,614	1,440,230		40.3	428,128	401,851	25,949	5.7	101,076	247,361	7.9	21,376	583,714
California	4,213,986	2,219,360	3,901,155	3,402,117		46.7	2,054,421	789,009	956,282	15.0		150,350	5.1	22,860	1,112,728
Colorado	1,712,633	190,000	1,765,127	1,700,547	13,406	35.9	5,717		5,717	1.2		170,877	2.0	18,085	
Connecticut	802,407	426,500	809,508	798,075	6,892	10.7	137,740		137,740	1.2				4,331	281,868
Delaware	477,680	230,849	474,326	406,045		7.4	54,180		54,180	.6	4,323		.7	7,313	176,669
Florida	1,410,008	501,200	1,639,226	1,398,151		18.5	87,633		87,633	2.5		9,883	.2	11,857	403,684
Georgia	2,724,020	1,272,373	1,499,273	1,490,222		57.7	842,228	806,580	35,648	16.9	238,197	284,090	12.1	189,622	958,635
Idaho	1,197,829	321,126	1,158,808	1,120,140	2,643	19.4	67,654	45,372	22,282	1.4		5,095	.5	32,317	291,106
Illinois	7,470,075	2,515,835	5,904,491	5,807,985		63.4	1,986,729	1,593,239	395,490	10.0	57,163	703,041	3.7	17,688	1,417,504
Indiana	4,287,050	2,035,585	2,944,301	2,896,840		60.9	1,159,142	1,124,013	34,951	10.1	213,658	566,958	16.4	52,538	1,433,677
Iowa	2,614,472	1,311,000	1,930,257	1,839,364	7,085	53.8	762,607	629,108	96,989	8.8	146,000	418,135	11.1		768,792
Kansas	2,622,401	1,432,949	2,232,396	2,221,567	2,442	38.7	934,239	275,108	514,877	9.7		915,630	8.2	25,726	
Kentucky	1,927,828	954,578	1,351,479	1,329,509		30.8	636,470	503,813	128,329	4.7	94,606	253,156	7.3		573,094
Louisiana	1,718,577	744,560	680,143	679,010		17.6	944,729	861,500	56,548	11.6	162,272	286,200	8.0	15,795	401,813
Maine	909,878	490,045	845,836	840,043		16.4	47,071	47,071		.4		105,066	.8	22,764	384,979
Maryland	891,132	452,515	388,284	384,134		4.1	911,650	98,129		.4	54,838		.2	354,031	452,515
Massachusetts	5,007,199	847,600	1,915,107	1,873,562		12.3	3,073,328	2,996,104	52,248	5.4		172,541	1.3	137,533	622,811
Michigan	3,500,638	1,613,142	3,211,863	3,063,989	101,950	39.0	1,349,600	412,750	898,950	8.8	14,950	406,800	10.5	8,949	205,442
Minnesota	3,719,143	1,421,494	3,245,306	3,018,514	195,446	108.1	370,010	155,856	205,954	10.1		173,198	6.5	544,773	846,397
Mississippi	1,744,669	885,056	654,198	614,044	27,695	24.5	775,721	668,228	78,493	21.9	324,748	58,100	9.1	137,649	720,768
Missouri	4,014,501	1,617,451	2,125,410	2,054,053		48.7	2,024,272	1,814,926	151,712	14.0	26,513	42,197	1.2	121,009	1,423,542
Montana	1,115,962	113,092	1,053,554	1,050,439		32.4	65,264	34,716	5,994	4.5	8,796	65,686	3.2	22,010	41,412
Nebraska	1,957,240	991,091	2,087,182	1,947,051	122,489	35.9	280,685		280,685	4.2	121	455,955	9.6	10,069	131,961
Nevada	500,051	100,000	494,565	474,754		8.8	65,438	16,107	49,331	1.5		1,000		9,190	49,668
New Hampshire	740,335	242,366	726,187	668,776	54,054	15.9	203,382	71,559	131,613	4.8					56,699
New Jersey	3,117,921	1,809,500	2,457,304	2,327,022		21.0	1,260,270	764,347	381,132	6.0		196,988	.5	26,552	1,231,380
New Mexico	1,674,158	529,506	1,381,103	1,381,103		31.3	373,264	193,167	180,097	8.9	8,234	69,432	1.7	91,655	279,977
New York	8,255,661	3,756,621	6,244,829	5,886,964		53.2	4,348,403	2,296,556	1,886,900	24.5		1,145,600	7.2	72,141	724,121
North Carolina	2,380,573	1,210,236	2,064,467	2,024,858	31,970	74.4	260,570	160,768	61,408	9.4	160,316	411,315	9.1	34,632	705,543
North Dakota	1,451,112	734,742	1,020,206	1,013,982		43.1	197,078	121,828	75,250	7.2	287,300	152,859	26.7	28,002	506,633
Ohio	4,335,686	2,359,503	4,531,914	4,019,218	15,000	57.8	999,430	226,500	677,980	10.7		1,027,230	10.6	89,968	639,293
Oklahoma	2,304,200	1,171,295	1,756,877	1,723,097		38.3	670,541	551,113	115,462	10.4		485,409	5.5	29,989	570,424
Oregon	1,526,724	867,977	1,484,039	1,460,758		27.8	187,504	53,905	112,979	2.6	518	462,181	9.7	11,543	292,816
Pennsylvania	4,854,988	2,397,703	3,509,074	3,279,974	84,056	55.0	1,788,530	1,480,091	226,563	15.4	32,000	1,456,307	15.0	62,923	630,777
Rhode Island	579,625	255,000	527,914	527,015		7.4	36,001		36,001	.6		68,999	.9	52,610	150,000
South Carolina	1,364,791	692,738	971,452	970,032		32.2	306,577	300,628	5,949	12.0	22,715	64,645	1.9	71,416	622,144
South Dakota	1,502,870	761,911	1,050,815	1,050,814		35.0	113,093	111,732	1,361	6.4	99,383	101,328	6.0	240,940	659,222
Tennessee	2,123,155	1,121,790	1,567,518	1,559,283		22.9	650,511	450,120	200,391	6.0	106,005	228,141	3.5	7,747	693,258
Texas	6,642,863	1,795,000	4,430,592	4,324,781		108.0	2,245,677	2,031,432	49,955	17.6	125,527	290,639	17.5	161,123	1,454,406
Utah	778,826	533,173	748,473	649,487	65,900	20.2	200,559	124,000	71,000	2.3	5,130	245,000	6.3	209	151,273
Vermont	500,509	240,611	418,799	403,261		11.9	185,602	97,248	77,285	3.9		84,715	1.4		78,611
Virginia	2,008,458	941,347	1,327,270	1,235,161	62,582	25.7	868,532	458,925	214,185	6.6	39,713	183,075	4.1	274,660	481,505
Washington	1,977,260	776,603	1,964,391	1,908,303	37,128	32.7	387,884		387,884	10.3	36,458	142,478	2.4	32,499	209,113
West Virginia	1,342,270	570,085	875,234	861,676	13,293	16.1	493,653	453,304	14,816	5.3		16,863	.6	27,289	525,113
Wisconsin	2,596,143	1,293,455	2,505,029	2,445,283	15,575	52.3	377,558	116,488	261,070	7.0		277,525	7.1	34,373	739,284
Wyoming	1,125,332	22,877	1,020,569	1,018,231		22.3	114,311	107,101	6,629	2.5		10,287	.7		5,961
District of Columbia	968,235	243,460	930,696	704,305	226,391	6.5	250,164	250,164		.2				13,765	17,070
Hawaii															
TOTALS	115,771,118	49,248,077	89,318,109	85,296,711	1,094,993	1,690.2	36,681,384	24,635,435	9,595,416	384.7	2,499,782	12,749,525	266.5	3,339,190	25,808,143

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3 - PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF FEBRUARY 28, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 847,621	$ 847,621		63.4	$ 1,442,247	$ 1,139,933	$ 302,314	103.0		$ 317,170	21.1	$ 44,898	$ 445,477
Arizona	525,423	998,032	530,237	517,610		42.3	337,581	7,813	285,282	22.9		56,348	7.7		656,401
Arkansas	1,449,634	857,024	1,107,252	1,103,900		140.1	367,359	267,263	99,454	38.6	$ 5,473	187,863	29.0	72,998	569,707
California	3,480,440	1,999,203	3,583,430	2,984,134		164.3	1,179,445	494,605	568,455	33.2		409,978	12.6	1,700	1,020,769
Colorado	1,718,632	871,502	1,754,711	1,608,632	$ 43,447	167.2	984,976	110,000	470,277	155.7		80,093	4.4		277,685
Connecticut	659,120	420,868					887,796	659,120	228,880	19.0		11,129	.4		186,859
Delaware	443,864	230,849	295,307	218,551	72,707	26.7	381,126	230,313	118,329	33.0					34,813
Florida	1,307,815	1,043,543	1,282,679	1,274,108		74.8	373,252		373,252	22.0		280,390	13.1	28,708	389,901
Georgia	2,320,973	1,278,373	1,202,043	1,199,035		86.7	1,038,291	916,123	122,168	70.3	33,126	133,143	17.6	172,689	1,023,062
Idaho	1,121,562	824,450	1,310,667	1,108,790	60,449	156.1	434,438		429,147	49.3		30,000	3.2	12,772	304,254
Illinois	5,652,228	3,345,555	1,948,518	1,932,204		124.0	5,188,701	3,610,926	1,577,775	278.5	99,933	1,765,332	80.1	9,165	2,419
Indiana	731,872	209,900	404,572	404,572		44.2	272,102	272,102		40.7	48,449	106,780	14.2	6,749	103,120
Iowa	2,413,358	1,590,000	2,058,296	1,931,498	67,450	295.1	1,261,008	424,850	675,200	208.4		643,150	147.8	57,010	204,200
Kansas	2,522,401	1,330,595	1,953,975	1,876,926	65,466	202.0	1,283,516	637,717	645,799	82.0	7,758	619,330	31.1		
Kentucky	1,837,926	1,336,409	1,812,919	1,720,166	16,263	210.0	819,299	107,202	700,434	87.6		619,712	95.3	10,558	
Louisiana	1,398,862	838,953	960,666	959,844		45.3	372,393	315,225	57,168	15.6	123,793	377,090	26.3		404,695
Maine	841,479	427,897	1,064,725	841,082	146,555	89.0	277,470		256,412	20.9		16,526	.7	1,397	8,404
Maryland	891,132	1,067,934	661,949	640,929		49.8	447,350	224,250	223,100	25.5	20,419	413,720	12.1	5,534	431,113
Massachusetts	486,185	870,000	469,741	469,741		15.2						115,370	5.5	18,443	754,631
Michigan	3,184,057	1,613,142	2,869,111	2,836,656	16,400	205.6	1,032,877	341,727	676,250	40.6		863,850	43.0	5,674	56,642
Minnesota	2,376,415	1,361,813	2,324,738	2,210,097	68,916	256.7	987,215	155,444	699,671	104.4		325,120	31.7	10,875	268,107
Mississippi	1,744,669	354,023	725,584	725,584		86.2	879,472	879,472		71.5	64,884		3.1	74,729	354,023
Missouri	2,923,273	2,423,863	2,871,931	2,687,722	109,686	584.5	836,646	158,005	633,388	189.3	77,546	887,618	127.1		793,171
Montana	1,859,937	942,434	1,809,318	1,795,045	12,644	226.5	294,173		294,173	18.3		556,610	63.7	64,892	79,007
Nebraska	1,957,240	991,091	2,108,619	1,957,240	147,789	402.5	536,114		536,114	42.6		227,036	43.8		80,151
Nevada	1,136,479	852,000	1,242,422	1,117,890	75,273	140.1	274,671		274,671	25.9		55,784	19.1	18,589	446,273
New Hampshire	477,385	242,365	543,721	447,963	51,459	27.9	114,607	29,000	82,590	5.9		57,479	3.4	422	50,337
New Jersey	55,099	460,000	56,528	55,099		.5						111,963	1.7		348,037
New Mexico	1,272,129	735,425	1,226,434	1,226,434		207.4	464,767	45,695	419,072	62.3		172,911	16.5		143,443
New York	3,608,768	3,822,700	3,320,216	2,955,796	28,200	83.8	3,743,820	625,700	2,318,900	171.8		1,172,328	115.0	27,272	303,272
North Carolina	2,380,573	1,590,637	2,155,446	2,154,669		224.3	1,062,973	215,387	847,586	111.4		431,154	57.7	10,517	311,896
North Dakota	1,451,112	734,741	903,913	903,913		280.1	263,581	263,581		73.2	220,451	245,641	132.2	67,167	489,061
Ohio	3,871,148	1,966,253	3,987,074	3,720,866	10,200	299.2	542,460	73,810	466,650	77.0		839,470	26.5	76,472	649,933
Oklahoma	2,304,199	1,171,295	1,821,283	1,719,586		224.9	1,263,439	576,850	584,502	74.6	5,479	183,973	15.3	2,085	402,320
Oregon	1,526,724	777,096	1,710,431	1,507,198	23,904	112.0	628,496	19,526	568,588	46.0		167,003	13.2		17,571
Pennsylvania	7,344,302	2,639,003	6,445,595	6,184,322	81,302	542.9	2,866,950	1,160,000	1,672,149	204.7		686,602	18.0		195,340
Rhode Island	439,716	295,000	414,120	404,637		33.2	262,140		262,140	6.7				35,078	32,860
South Carolina	1,354,791	692,739	1,116,509	1,060,256	56,254	119.6	750,079	255,654	450,646	97.3		185,539	25.0	48,362	
South Dakota	1,500,870	751,911	1,188,476	1,140,303	48,151	333.5	335,694	310,785	24,909	94.1	51,782	104,547	69.4		584,304
Tennessee	2,123,155	1,075,748	1,352,642	1,314,948		111.9	1,064,587	729,642	335,045	53.8	4,503	120,771	[illegible]	74,051	[illegible]
Texas	6,012,513	3,632,000	5,995,221	5,523,540		753.6	1,610,472	456,546	1,149,778	92.6		865,256	33.4	27,431	[illegible]
Utah	1,043,677	633,173	1,125,881	955,732	114,300	185.6	357,024	92,945	198,373	61.1		93,000	11.8		157,000
Vermont	433,380	241,354	474,394	436,802	16,569	37.2	118,931		113,646	8.4		111,102	8.0	[illegible]	[illegible]
Virginia	1,649,920	941,347	1,598,958	1,536,960	8,753	210.8	380,878	114,349	266,747	21.9	11,450	[illegible]	[illegible]	[illegible]	[illegible]
Washington	[illegible]	776,503	1,071,774	1,043,594	7,095	63.7	389,538	36,153	34,156	40.7		[illegible]	7.7	938	[illegible]
West Virginia	1,118,553	570,583	733,462	7 1,270		41.9	404,913	359,084	45,829	15.2	25,237	123,331	5.5	[illegible]	[illegible]
Wisconsin	[illegible]	1,732,435	2,316,893	2,153,100	48,583	170.4	508,161	202,460	249,763	14.6	58,000	519,916	[illegible]	[illegible]	[illegible]
Wyoming	[illegible]	671,908	1,080,501	1,061,742		149.1	149,276		149,274	15.5	27,126	161,648	34.2	36,454	[illegible]
District of Columbia	[illegible]	730,382	1,041,683	911,763	139,920	8.7	234,139		234,139	2.6		147,150	1.6	38,471	[illegible]
Hawaii	[illegible]	351,000	177,718	177,718		4.9								9,389	[illegible]
TOTALS	[illegible]	56,244,601	79,089,024	74,273,308	1,538,235	8,125.4	39,706,763	16,519,257	21,012,735	3,150.2	895,409	14,170,934	1,596.1	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF FEBRUARY 28, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,132	$ 4,259,842	$ 7,765,261	$ 5,200,024	$ 35,889	403.4	$ 4,832,769	$ 2,901,738	$ 1,245,704	275.0		$ 876,548	42.5	$ 268,370	$ 2,101,701
Arizona	5,211,960	2,641,935	5,511,805	4,834,113	64,696	345.6	1,420,223	190,692	1,134,881	95.3	$ 130,379	387,234	36.3	56,776	1,055,125
Arkansas	6,748,335	3,428,049	5,650,138	4,937,669	137,101	335.3	2,646,864	1,467,326	913,313	118.1	146,112	648,173	42.4	197,228	1,729,462
California	15,647,364	7,932,206	16,594,173	13,216,328		488.7	7,034,983	2,359,819	2,995,838	120.9		1,489,818	83.5	71,207	3,446,550
Colorado	6,874,530	3,486,006	7,403,654	6,676,138	497,351	384.0	2,878,863	170,627	2,168,142	247.1	9,680	542,229	17.7	18,085	277,685
Connecticut	2,865,740	1,454,868	1,607,120	1,593,354	6,892	24.8	2,350,437	1,268,054	814,019	41.9		165,229	2.2	4,331	468,728
Delaware	1,819,088	923,395	1,679,822	1,554,257	108,883	72.2	864,448	230,313	586,473	44.3	13,056		.7	21,462	228,039
Florida	5,231,834	2,661,343	5,932,439	4,852,821		202.2	1,527,866	264,471	1,195,844	67.0		345,851	13.7	114,542	1,119,648
Georgia	10,091,186	5,111,491	6,341,622	6,136,646		397.1	4,008,199	3,116,529	856,670	186.1	313,092	1,407,988	91.2	524,919	2,846,832
Idaho	4,486,249	2,277,486	4,612,439	4,203,245	160,418	359.7	1,045,754	216,522	811,745	80.6	21,392	197,192	21.4	45,089	1,108,131
Illinois	17,576,770	8,921,401	9,847,750	9,699,179	19,269	225.9	10,188,126	7,625,811	2,562,715	323.1	193,141	3,533,300	105.5	58,640	2,806,117
Indiana	10,037,843	5,068,963	6,594,642	6,503,638		212.3	3,237,339	3,088,046	148,404	91.2	320,868	2,654,275	157.5	125,291	2,266,284
Iowa	10,055,660	5,118,361	8,807,984	8,372,101	108,955	637.4	3,843,794	1,434,558	2,114,462	328.9	155,800	1,568,349	183.5	93,201	1,326,596
Kansas	10,089,604	5,117,675	9,496,816	9,030,391	239,277	787.1	3,821,181	969,225	2,707,102	257.7	7,758	2,171,296	85.6	82,230	
Kentucky	7,517,359	3,818,311	6,787,007	6,402,927	49,834	484.7	2,098,345	900,934	1,129,266	142.9	188,982	1,374,710	149.8	24,516	1,264,500
Louisiana	5,828,591	2,963,932	3,397,085	3,391,749		136.8	3,209,113	2,082,199	586,431	39.7	331,418	1,361,642	53.8	23,225	1,015,859
Maine	3,369,917	1,711,586	3,272,553	3,007,549	146,556	149.2	1,127,115	286,526	819,530	34.7	12,524	318,993	8.3	63,318	426,507
Maryland	3,564,527	1,810,058	1,841,856	1,803,195	3,843	69.0	2,245,878	1,093,839	338,518	45.9	114,392	511,450	14.0	553,101	956,248
Massachusetts	6,597,100	3,350,474	3,793,878	3,359,383		65.0	3,635,361	3,048,791	509,772	14.7		840,038	16.9	188,926	2,000,664
Michigan	12,736,227	6,452,568	10,871,201	10,594,483	118,350	468.0	5,125,302	2,102,677	2,955,025	151.2	14,950	2,898,625	123.4	24,117	480,568
Minnesota	10,656,569	5,425,551	11,207,797	9,572,776	1,456,525	1,229.5	2,281,294	490,356	1,591,838	244.6		1,075,304	108.1	593,437	1,301,883
Mississippi	6,978,675	3,540,227	5,726,616	3,672,338	115,300	334.7	3,763,766	2,521,747	418,398	210.4	422,453	1,109,006	66.8	362,137	1,897,523
Missouri	12,180,306	6,173,740	9,658,228	8,868,843	109,685	821.1	5,350,290	3,038,009	1,988,273	273.7	104,060	1,656,488	152.5	169,394	2,419,292
Montana	7,439,748	3,769,734	8,356,020	7,305,204	479,518	685.2	2,112,208	38,846	1,979,851	193.1	8,796	931,912	101.1	86,902	378,453
Nebraska	7,828,961	3,964,364	9,337,216	7,797,128	324,288	811.9	2,377,007	21,644	2,008,983	122.3	121	1,375,937	86.0	10,069	255,156
Nevada	4,545,917	2,302,356	4,570,926	4,297,146	151,311	417.6	1,090,592	124,878	965,714	128.4	17,734	71,539	21.7	106,158	1,113,791
New Hampshire	1,909,839	969,462	1,908,592	1,729,128	105,513	54.7	743,561	180,288	538,983	21.9		174,246	4.7	422	150,721
New Jersey	6,346,039	3,220,879	4,225,064	4,073,819		53.0	2,946,388	2,236,389	406,050	22.7		641,860	5.7	35,831	2,172,969
New Mexico	5,792,935	2,941,700	5,640,589	5,368,485	128,175	536.2	2,096,431	324,562	1,700,975	167.8	8,234	242,343	18.2	91,655	870,208
New York	22,330,101	11,327,921	19,743,912	17,237,397	81,200	347.3	15,725,151	4,932,326	6,597,400	331.1		3,246,748	134.0	160,378	1,402,573
North Carolina	9,522,293	4,840,941	8,857,013	7,763,894	241,549	880.3	2,602,226	980,470	1,312,134	256.8	409,960	974,935	98.5	367,970	2,312,323
North Dakota	5,804,448	2,938,967	5,054,005	4,563,243	58,556	1,347.1	827,434	438,262	315,109	213.4	555,575	948,951	444.7	247,368	1,616,350
Ohio	15,484,592	7,865,012	15,993,193	14,800,011	25,200	549.5	3,477,510	300,310	2,843,240	133.1		3,212,275	60.0	384,271	1,734,296
Oklahoma	9,216,798	4,685,180	7,393,835	7,156,754	14,570	541.5	4,251,760	2,013,799	2,010,231	183.4	5,479	1,167,280	42.1	40,766	1,493,099
Oregon	6,106,896	3,097,814	6,533,951	6,007,786	32,831	322.8	1,959,245	87,050	1,754,193	99.0	518	843,674	32.7	11,543	467,115
Pennsylvania	18,891,004	9,590,788	15,717,766	14,969,412	263,783	721.0	8,732,931	3,738,104	4,664,974	288.8	32,865	3,650,677	62.1	150,622	1,011,354
Rhode Island	1,998,708	1,014,572	1,910,039	1,831,280		61.1	840,606	46,205	712,271	20.9		94,193	1.6	121,223	208,108
South Carolina	5,459,165	2,770,954	4,288,734	4,210,385	56,253	346.0	1,986,612	983,706	919,474	184.6	43,635	251,262	26.9	221,440	1,543,964
South Dakota	6,011,479	3,047,643	5,002,910	4,437,854	83,020	823.4	1,144,968	987,263	146,051	273.9	289,114	1,097,479	221.4	297,247	1,721,093
Tennessee	8,492,619	4,302,991	7,348,618	6,616,081	64,152	310.0	2,736,718	1,591,558	1,048,760	92.9	167,316	1,086,383	33.8	117,664	2,103,697
Texas	24,244,024	12,291,253	21,754,790	20,689,120		1,843.0	7,470,470	3,212,786	4,049,596	393.5	143,208	2,662,835	241.1	198,909	5,578,822
Utah	4,194,708	2,132,691	4,696,988	3,884,292	546,200	443.6	1,348,857	301,578	765,473	124.9	5,130	346,000	18.3	3,708	475,018
Vermont	1,867,573	948,007	1,863,902	1,749,676	45,033	97.0	581,752	107,918	440,045	26.2		338,082	14.6	9,979	124,847
Virginia	7,416,757	3,765,387	6,482,819	6,097,107	89,507	387.6	2,531,708	649,689	1,590,782	76.7	181,648	935,593	77.5	488,313	1,149,506
Washington	6,115,867	3,106,412	5,808,044	5,507,987	240,300	195.8	2,380,842	471,083	1,737,482	78.6	67,122	483,407	12.9	69,675	645,223
West Virginia	4,474,234	2,280,335	3,556,146	3,438,849	74,185	129.2	1,452,784	924,058	486,302	40.5	25,237	430,436	15.2	86,091	1,289,411
Wisconsin	9,724,881	4,941,837	9,258,345	8,914,763	67,483	435.7	1,688,335	558,390	973,458	64.4	202,828	1,583,343	80.0	48,901	2,317,554
Wyoming	4,501,327	2,287,712	4,411,560	4,115,457	85,400	648.2	1,494,888	316,303	1,151,835	162.1	27,126	620,663	127.1	42,441	429,314
District of Columbia	1,918,469	973,842	1,962,379	1,616,069	366,310	15.2	484,303	250,164	234,139	2.8		147,150	1.6	52,236	226,243
Hawaii	1,871,062	949,778	526,922	428,481		17.3	1,826,261	1,428,169		27.2				14,412	949,778
TOTALS	394,000,000	200,000,000	346,614,414	314,109,555	7,023,161	21,650.7	155,448,458	68,114,607	71,945,469	7,166.0	4,691,703	54,693,542	3,560.8	7,084,135	66,337,828

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 2 APRIL 1935

A TRAFFIC SURVEY STATION IN NEW JERSEY

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 16, No. 2 April 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

SOME CHARACTERISTICS OF TRAFFIC ON NEW JERSEY HIGHWAYS

EXTRACTS FROM A REPORT ON THE NEW JERSEY TRAFFIC SURVEY[1]

Reported by L. E. PEABODY, Senior Highway Economist, Division of Highway Transport, Bureau of Public Roads

COLLECTING DATA ON CHARACTERISTICS OF TRUCK TRAFFIC

FIELD observations in the New Jersey traffic survey were carried on at 352 observation stations located over the entire State highway system and on the principal county routes. Observations were made from August 1932 to August 1933. Traffic data were recorded upon more than 1,000 sections of highway at the stations with locations as shown in figure 1.

Traffic volumes of all motor vehicles, and of trucks, busses, and foreign vehicles are presented graphically in figures 2, 3, 4, and 5. Passenger cars were 86 percent of all observed vehicles, trucks 12 percent, and busses 2 percent. Heaviest traffic volumes were at the Holland Tunnel, Camden-Philadelphia Bridge, the High-Level Viaduct between Newark and Jersey City and on U S 1 southeast of Elizabeth. Average daily traffic exceeded 25,000 vehicles at all these locations, while west of Montclair on the Montclair-Caldwell Highway and west of Jersey City on the Newark Turnpike there were between 24,000 and 25,000 vehicles per day.

HEAVY PEAK TRAFFIC FOUND ON A NUMBER OF ROUTES

Peak traffic exceeded 50,000 vehicles per day on the Philadelphia-Camden Bridge and was more than 40,000 per day at other locations. Routes leading to shore resorts had the highest ratios of maximum daily traffic to average daily traffic. Near Weymouth on N J 42, the ratio exceeded 700 percent and ratios in excess of 500 percent were found southeast of Cedar Bridge on N J S–40 toward Long Beach and on a county route connecting with Atlantic Highlands southwest of New Monmouth. These ratios are of special significance in considering pavement width and right-of-way width requirements. Eighty-four sections of highway throughout the State were found with ratios of peak to average traffic in excess of 300 percent.

The heaviest traffic volume was on U S 1 between Trenton and the Holland Tunnel which averaged more than 16,000 vehicles per day throughout its length. Other routes with average volumes greater than 5,000 per day include: N J 4, George Washington Bridge to Paterson; county road, West Caldwell to Belleville to Jersey City; county road, N J S–1, N J 6, and N J 9–W, Bayonne to Coxiesville to Alpine to the New York State line; U S 9–W and county road, Hoboken to Leonia to New York State line; N J 5–N and 24, Mount Tabor to Morristown to Newark; N J 29, Hillside to Somerville; U S 22, Elizabeth to Somerville to Phillipsburg; county road, East Rutherford to Paterson to Pompton to Lakeside; N J 27, Trenton to Newark; N J 35, South Amboy to Point Pleasant to Lakewood; N J 2, Harrison to the New York State line; U S 30 and county road, Camden to Atlantic City; N J S–41, Berlin to Palmyra; N J 6 and S–6, Fort Lee to Paterson to Delaware; county road between Fort Lee and junction with N J 6 west of Bogota; N J 25, New Brunswick to Bordentown to Camden; U S 130, Bordentown to Trenton; N J 42 and county road, Camden to Atlantic City; N J 23 and S–N and county road, Newark to New York State line; a total of 20 sections or 675 miles of highway. There are over 1,000 trucks per day on 4 of these routes, with the largest average, 2,690 trucks per

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[1] The full report [illegible] New Jersey State Highway Department [illegible] of Public Roads.

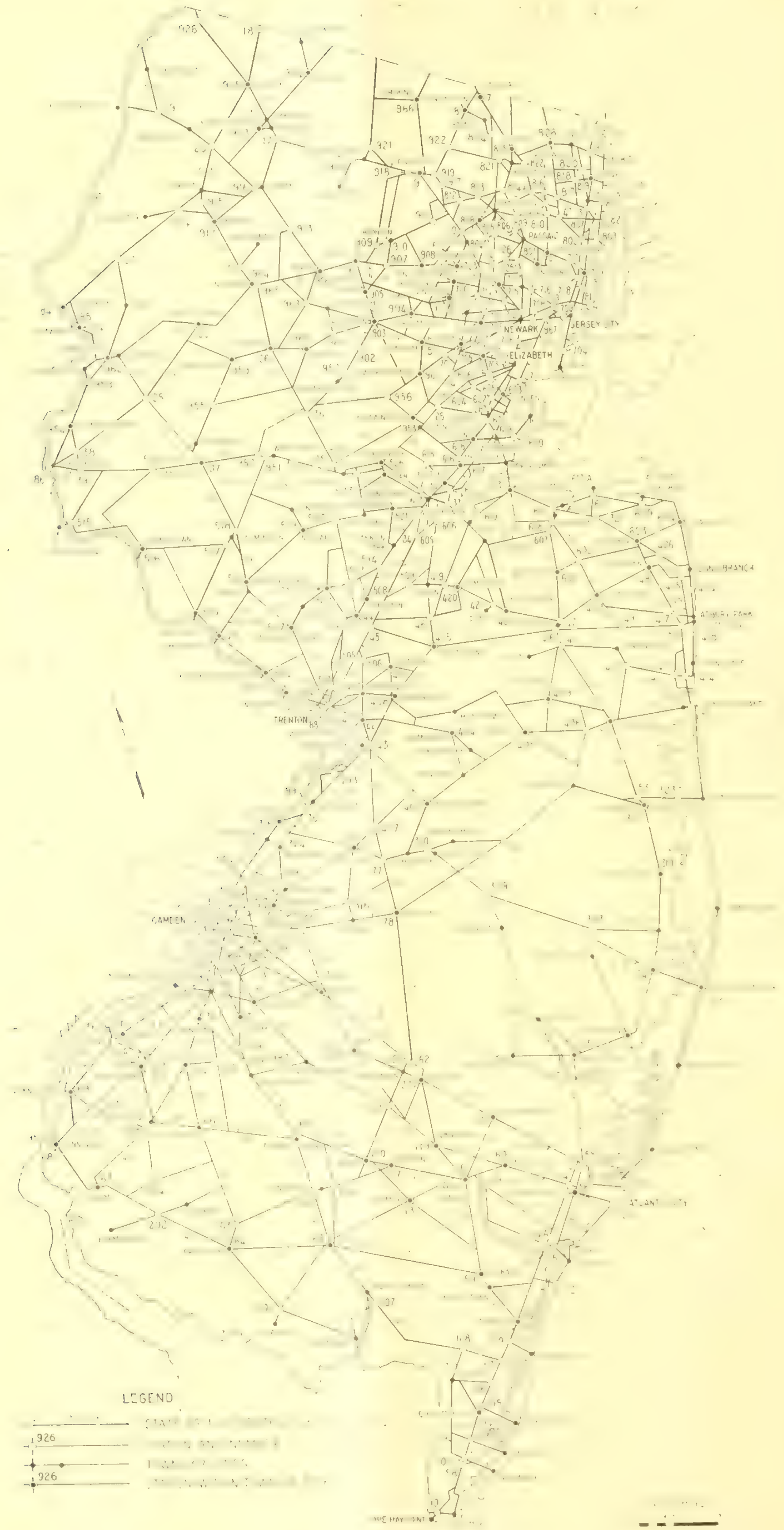


Figure 1.—Location of Traffic Survey Stations on State and Important County Highways.

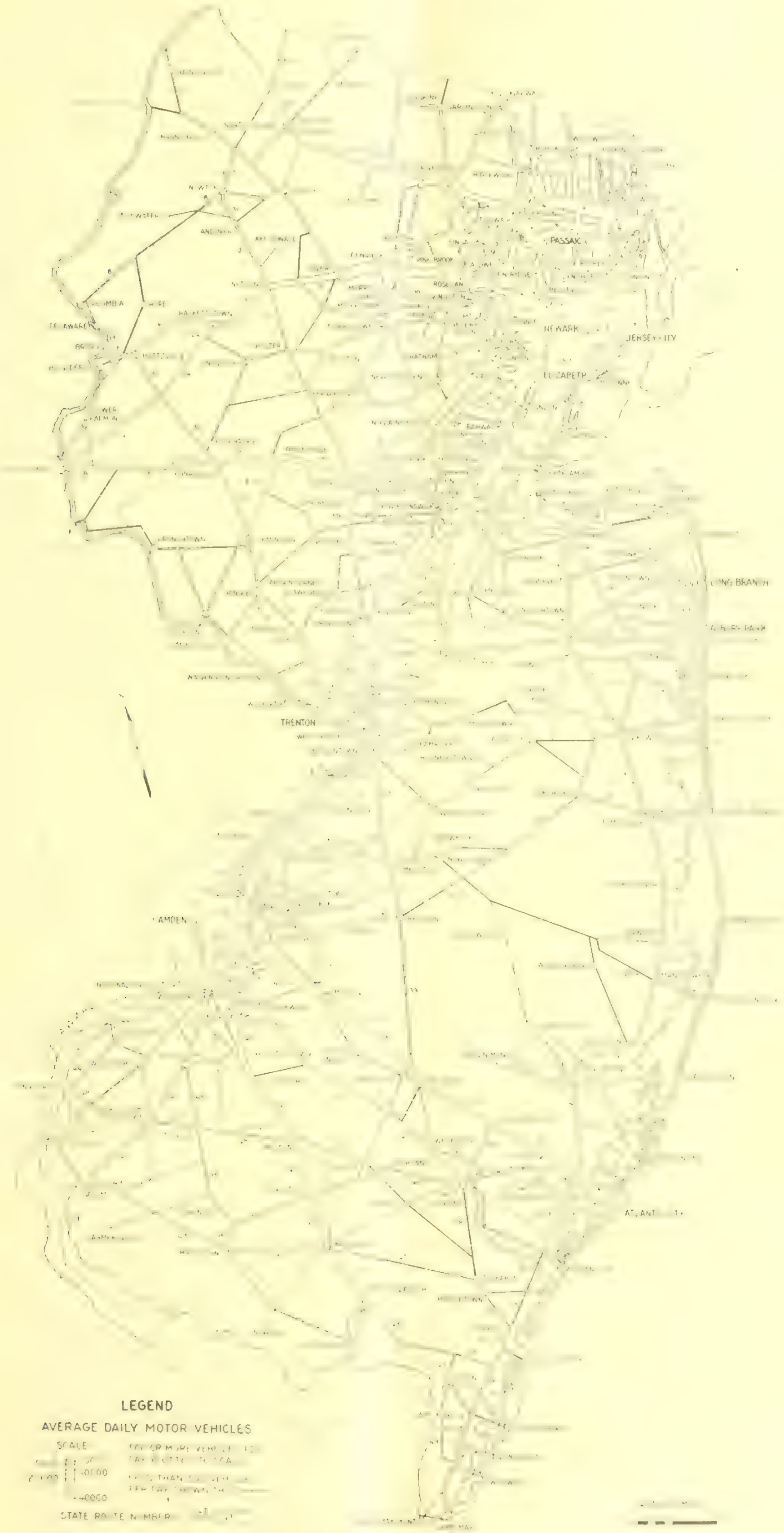


Figure 2.—Average Daily Motor Vehicle Traffic on State and Important County Highways.

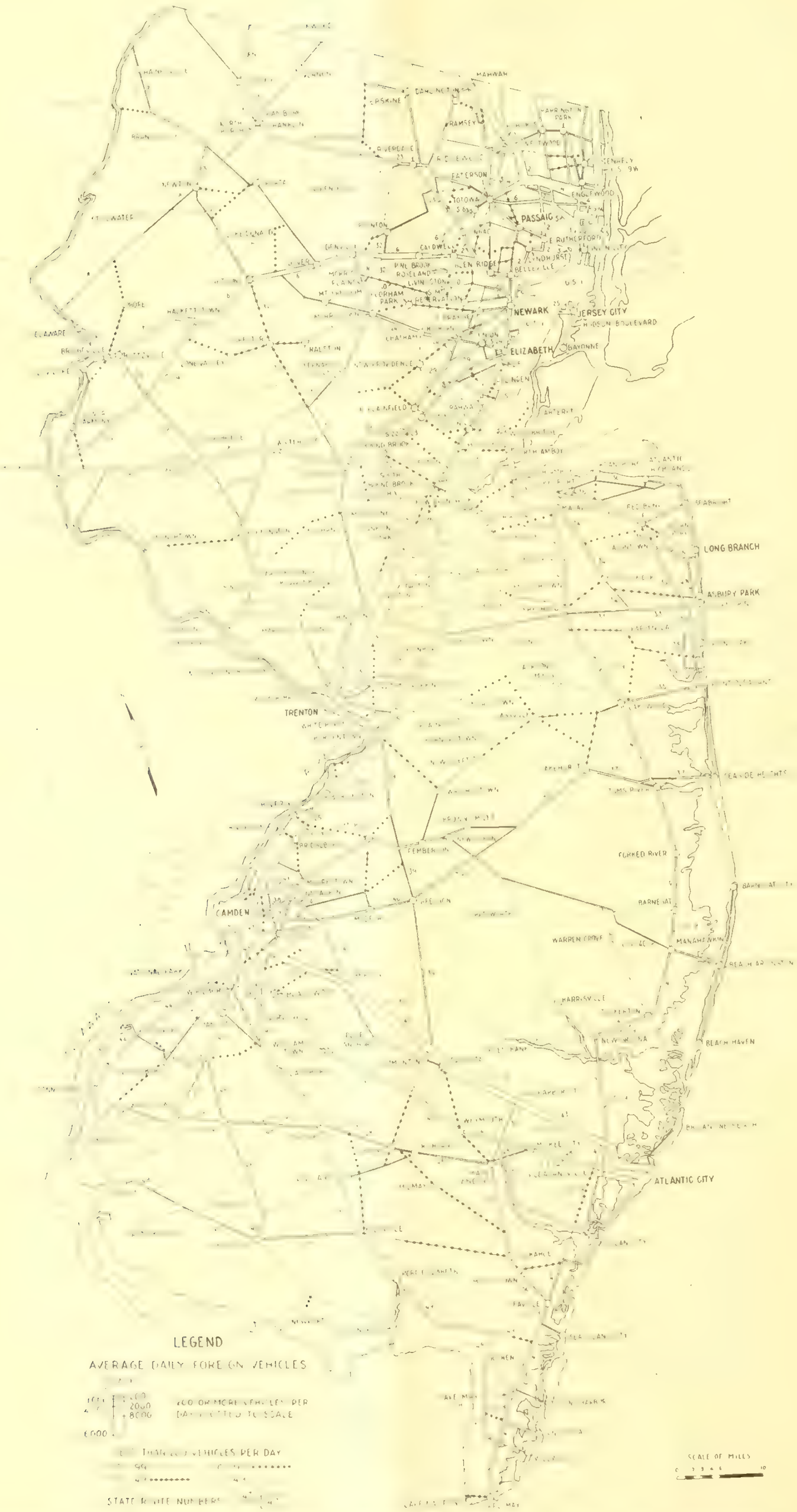


FIGURE 3.—AVERAGE DAILY DENSITY OF FOREIGN VEHICLE TRAFFIC ON STATE AND IMPORTANT COUNTY HIGHWAYS.

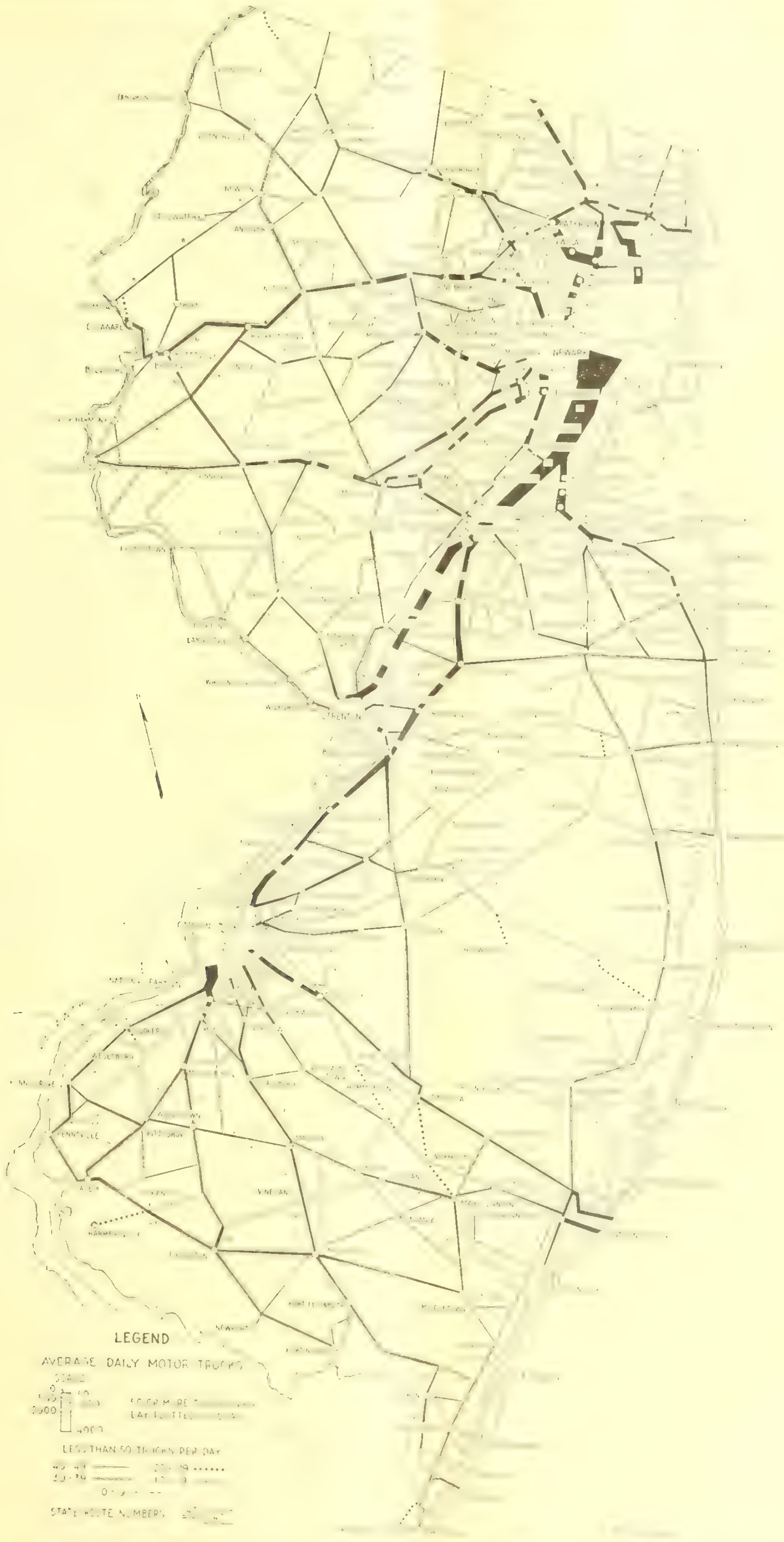


Figure 4.—Average Daily Density of Motor Truck Traffic on State and Important County Highways. Number of Trucks of More than 1½ Tons Capacity are Indicated by Solid Black Within the Truck Flow Band, and are Shown only for those Routes where Detailed Information was Obtained in the Field. Truck Capacities on Sections of Highway Within Closely Built Urban Areas are not Shown where Intersections with Cross Routes are Frequent.

day, on U S 1 between the High-Level Viaduct and Trenton.

Figure 2 shows the average daily traffic on State and important county highways.

Traffic volume was greatest in August—about 132 percent of that of the average month. Foreign traffic varied more widely than local traffic, the range being from 52 to 177 percent of that of the average month. Local traffic varied from a low of 77 percent in February to a high of 122 percent in each of the 3 months of June, July, and August.

Foreign traffic had a large daily variation from a low of 94 percent of the average on Tuesdays and Thursdays to a maximum of 206 percent on Sundays, as compared with a range of 92 to 122 percent for local traffic.

NEW JERSEY HIGHWAYS CARRY A LARGE VOLUME OF FOREIGN TRAFFIC

The average daily traffic density of foreign vehicles is shown in figure 3. Foreign vehicles averaged 18 percent of all observed vehicles. Nearly one-half (46 percent) of foreign vehicles were from New York, 41 percent from Pennsylvania, and not quite 13 percent were from other States. They follow well-known State and county highways and are most prominent on cross-State routes. Their volume has no fixed relation to total traffic. For example, U S 9-W from Jersey City to the northern New Jersey State line had a traffic of 11,821 vehicles per day, of which 26 percent was foreign, while the county road from West Caldwell to Jersey City—a direct connection from N J 6 to the latter city, though comparatively unknown to tourists—had practically the same traffic volume, and a percentage of foreign traffic of but 13. Similarly, U S 30 from Camden to Atlantic City, N J 6 and S 6 from Fort Lee to the Delaware line, each with an average traffic practically equal to that of N J 35 from South Amboy to Lakewood, carried 44 and 22 percent of foreign traffic as against 10 percent on N J 35.

THROUGH ROUTES CARRY LARGE VOLUME OF TRUCK TRAFFIC

The average daily density of motor truck traffic is shown in figure 4. Truck traffic in New Jersey was 12 percent of all motor traffic, although there was considerable variation in the percentages on different routes. For example, on the Pennsylvania Railroad ferries at Camden trucks were more than one-half of all traffic and on the Reading ferries, 44 percent. The heaviest truck traffic was found on U S 1, exceeding 1,200 trucks per day at all points except the by-pass around New Brunswick.

Figure 5 shows the average daily density of motor bus traffic.

INTENSIVE USE MADE OF STATE SYSTEM

The average daily traffic on the New Jersey State highway system was 4,659, of which 3,996 were passenger vehicles. This represents an annual use of the State system of 2,609 million vehicle-miles, or approximately 81 percent of the annual use of the Michigan trunk lines, although average use per mile in New Jersey is approximately four times that in Michigan.

Use per mile of the State system was greatest in Hudson, Union, Bergen, Camden, and Middlesex Counties—listed in order of magnitude. The average daily traffic was in excess of 8,000 vehicles in all five counties, with an average of 16,608 vehicles daily on State highways in Hudson County. Population per square mile is heaviest in these counties and follows the same order as the use of the highways. Hudson County has 16,063 persons per square mile and all of these counties, except Middlesex, have more than 1,000 persons per square mile. Average daily traffic was least in Cape May, Salem, and Sussex Counties, but in none of these does average traffic on State highways drop below 1,600 per day, indicating that even in counties of relatively light population density, usage of State highways is relatively high.

Foreign passenger cars constitute a much higher percentage of the total traffic on the New Jersey State highway system than they do in many other eastern States. For the whole State of New Jersey the percentage of highway use by foreign passenger cars was 24.3, as compared with 10.2 percent in Ohio and 10.8 in Michigan. This percentage is exceeded in several of the western States, but foreign passenger-car-miles in all such States are less than one-third of the amount in New Jersey.

Similar data were obtained on a portion of the county highways of New Jersey, but since only the important county routes were included in the survey, a direct comparison between State and county routes would be inaccurate. Although the coverage of county roads was incomplete some of the proportions are worth noting. Foreign passenger vehicles constituted 12 percent of the passenger vehicles on county roads, less than half the percentage found on the State system. A comparison of the density of passenger vehicle traffic on State and county roads in certain of the counties indicates the importance of certain county routes. In Essex County the figures are 4,838 passenger vehicles daily on State highways, and 5,987 on county roads. In Hudson, Monmouth, Passaic, and Salem Counties the averages for the county roads are close to those for the State highways.

Use of the State system by passenger cars originating in local and adjacent counties was 71.8 percent of the total use in Essex, Hudson, Union, Passaic, Morris, and Bergen Counties, and averaged 51.8 percent in the remainder of the State. Despite the large volumes of foreign traffic that pour through these counties, which are in the New York metropolitan area, the local use of the State system was nearly 40 percent more than in the rest of the State.

In the resort counties of Atlantic, Cape May, and Warren the percentage of use of the State system by foreign cars was 40.7, as compared with 22.7 percent for the remainder of the State. The significance of such foreign use is greatly increased when it is noted that both Atlantic and Cape May Counties are removed from adjacent States and that all foreign cars must pass through other counties to reach these two. Nearly 43 percent of the total travel in these two counties was by foreign cars. Warren County is adjacent to Pennsylvania and so receives large numbers of local trips by passenger cars with foreign plates.

Monmouth, Ocean, and Sussex are largely resort counties and are much more heavily patronized by New Jersey residents than by those from other States. The proportion of passenger car use of the State system in these three counties by residents of nonadjacent counties was 35.4 percent, as compared with 14.2 percent for the remainder of the State.

ORIGIN AND DESTINATION OF TRAFFIC AT PRINCIPAL STATE OUTLETS STUDIED

Nearly 125,000 motor vehicles entered or left New Jersey each day by way of 15 principal river crossings.

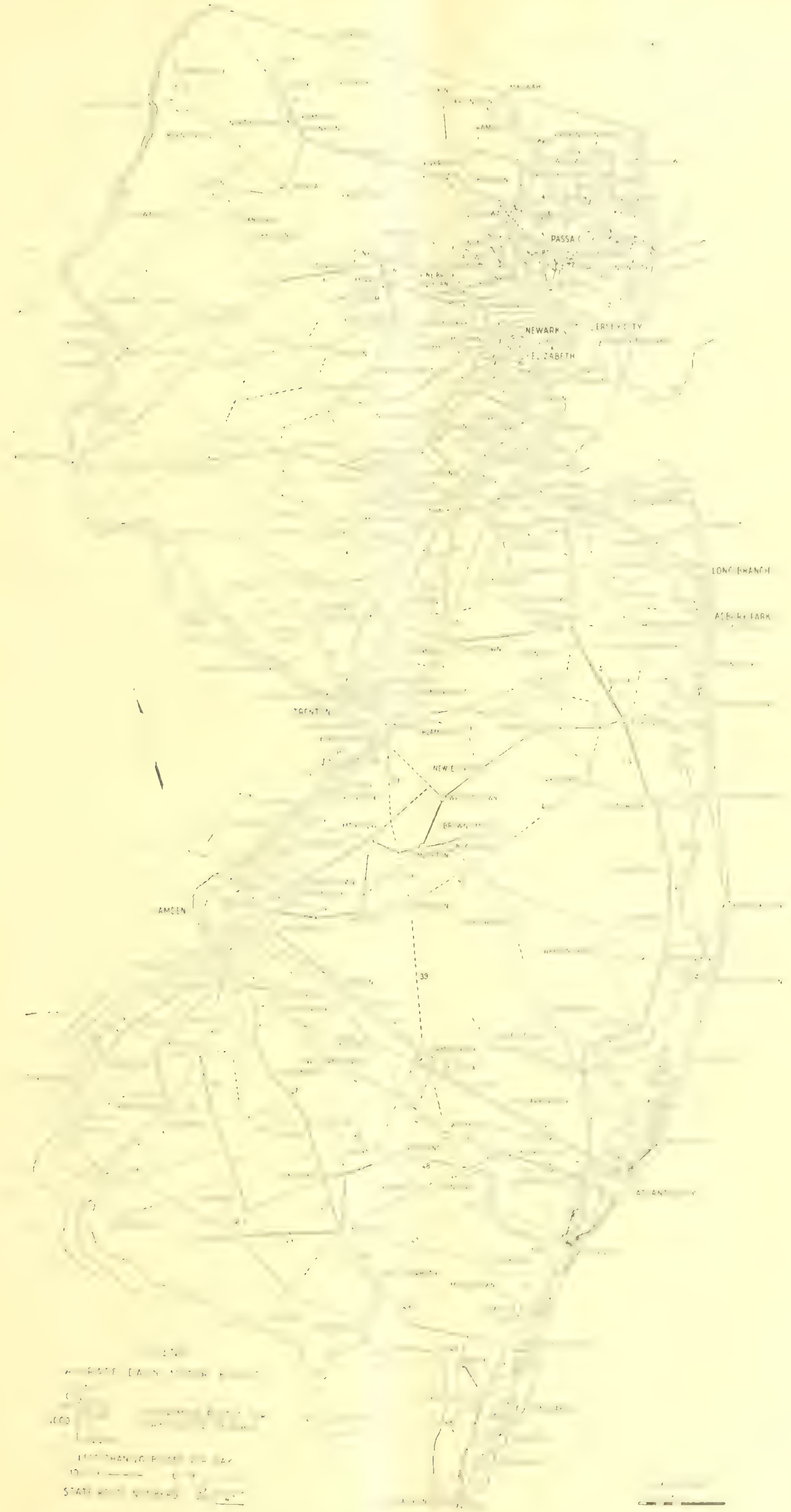
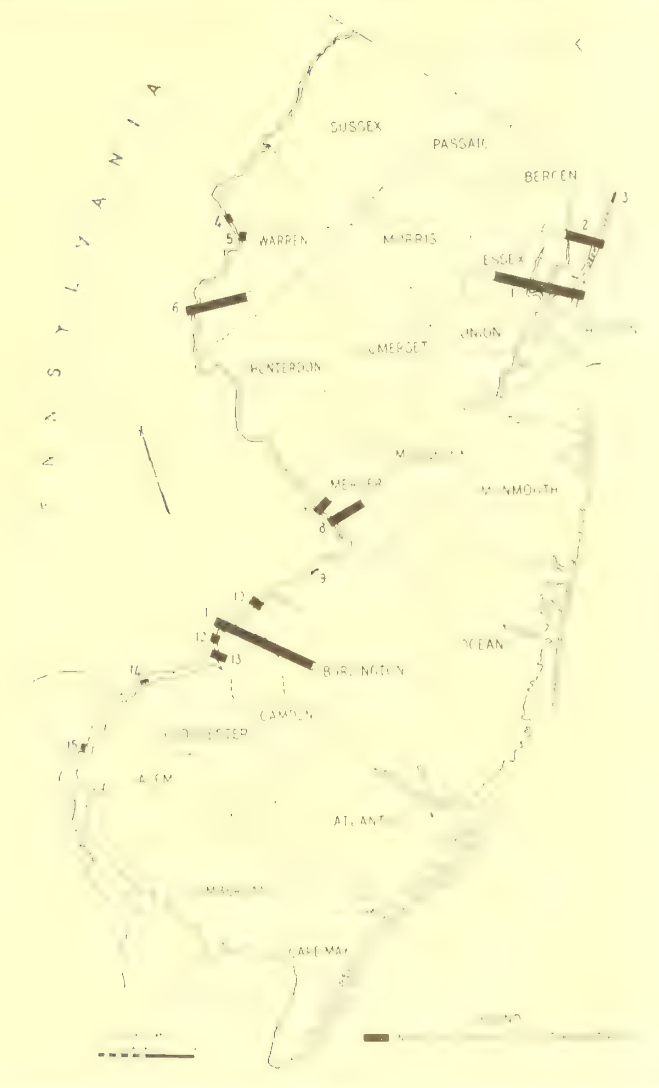


Figure 5.—Average Daily Density of Motor Bus Traffic on State and Important County Highways.



	Daily average traffic	Percent of total	
		New Jersey traffic	Through traffic
15 crossings, total	124, 277	83. 7	16. 3
Hudson River crossings			
1. Holland Tunnel	30, 036	18. 5	[illegible]
2. George Washington Bridge	15, 840	7. 8	5. 0
3. Alpine-Yonkers Ferry	808	. 4	. 3
Delaware River crossings			
4. Columbia-Portland Bridge	952	. 7	(1)
5. Delaware-Portland Bridge	2, 556	1. 2	. 9
6. Phillipsburg-Easton Bridge	16, 958	12. 5	1. 1
7. Trenton-Langhorne Bridge	6, 091	3. 6	1. 3
8. Trenton-Morrisville Bridge	11, 615	7. 8	1. 5
9. Burlington-Bristol Bridge	651	[illegible]	(1)
10. Palmyra-Philadelphia Bridge	3, 443	2. 7	(1)
11. Camden-Philadelphia Bridge	27, 491	21. 8	[illegible]
12. Camden-Philadelphia Ferry (Pennsylvania R. R.)	1, 938	1. 6	(1)
13. Camden-Philadelphia Ferry (Reading R. R.)	3, 775	3. 0	(1)
14. Bridgeport-Chester Ferry	762	. 6	(1)
15. Pennsville-Newcastle Ferry	1, 361	. 8	[illegible]

[1] Less than $\frac{1}{10}$ of 1 percent

FIGURE 6.—TRAFFIC ORIGINATING OR TERMINATING IN NEW JERSEY AND THROUGH TRAFFIC USING HUDSON AND DELAWARE RIVER CROSSINGS.

About 47,000 crossed the Hudson River on the George Washington Bridge, the Holland Tunnel, or the Alpine-Yonkers Ferry, and nearly 78,000 crossed the Delaware River at 12 points. Twenty-nine percent of the cars which crossed the Hudson represented through traffic, originating at points outside of New Jersey and passing through the State without stop-over. In contrast only 9 percent of the vehicles crossing the Delaware passed through New Jersey without stopping, and 91 percent either stopped or started in New Jersey.

The location of each crossing, together with the amounts of through traffic and New Jersey traffic, are shown in figure 6. The total length of each bar represents the relative part of total traffic using the crossing, while the black portion represents New Jersey traffic and the white portion through traffic. Traffic through the Holland Tunnel was greater than that at any other crossing in respect to both total and through traffic. The George Washington Bridge, although carrying only a little more than half the total traffic volume of the Holland Tunnel, had almost as much through traffic as the latter.

Relatively more New Jersey traffic crossed the Camden-Philadelphia Bridge than at any other crossing, but through traffic was comparatively unimportant at this crossing. Traffic at the Phillipsburg-Easton Bridge was greater in volume than that at the George Washington Bridge but was almost entirely local—80 percent of it either originated or terminated in the county in which the crossing is located, and only 8 percent was through traffic. The Delaware-Portland Bridge carried 42 percent through traffic, a greater proportion than any other crossing. One-fourth of all vehicles crossing the Trenton-Langhorne Bridge had both termini outside New Jersey, and one-sixth of all cars crossing the Trenton-Morrisville Bridge were of this class. Through traffic was relatively unimportant at the Columbia-Portland, Burlington-Bristol, and Palmyra-Philadelphia Bridges, at both railroad ferries between Camden and Philadelphia, and at the Bridgeport-Chester Ferry. More than one-fourth of the traffic over the Pennsville-New Castle Ferry was through traffic.

The relative importance of the contribution of each New Jersey locality to the traffic traversing the 15 principal Hudson and Delaware River crossings is given in detail for each county and principal city in table 1. This information is also presented graphically in figures 7 and 8, in which the areas of the circles are proportional to the percentage of total traffic which originated or terminated in the designated cities and counties. The greatest percentage of this traffic centered in Camden County, where 14 out of every hundred vehicles entering or leaving New Jersey each day by way of these principal crossings either ended or began their journeys. Warren County was the origin or destination of almost 12 percent of all such traffic, 10 vehicles out of the 12 representing traffic to or from Phillipsburg. Mercer County, which accounted for 10.5 percent of total principal river-crossing traffic, is third in importance in this classification, with Trenton taking more than 90 percent of total county traffic. More than 9 percent of total river-crossing traffic was to or from Essex County, with Newark alone taking more than half that volume. Atlantic and Hudson Counties each accounted for more than 6 percent of

Areas of circles are proportional to percentage of total traffic originating and terminating in designated localities. An asterisk indicates localities for which traffic was less than 0.1 percent. Values for these localities are included in general county total wherever possible. No traffic was reported for cities or counties on left bank. Through traffic, neither originating nor terminating in New Jersey, is shown only in the table above.

Daily average number of vehicles using these crossings, 124,277

	Number	Percent
Through traffic	20,282	[illegible]
New Jersey traffic	103,995	83.7
Principal counties:		
Camden	17,495	14.1
Warren	14,893	12.0
Mercer	13,056	10.5
Essex	11,342	[illegible]
Atlantic	8,000	6.4
Hudson	7,766	[illegible]
Bergen	6,186	5.0
Total	78,738	[illegible]
Other counties	25,257	20.3

FIGURE 7.- -AREAS SERVED BY FIFTEEN HUDSON AND DELAWARE RIVER CROSSINGS.

the total, and Bergen County, 5 percent. Traffic of Burlington, Gloucester, Passaic, and Union Counties each furnished between 2 and 4 percent of the total; Monmouth, Middlesex, Morris, Cumberland, and Cape May Counties, furnished between 1 and 2 percent each; and Ocean, Salem, Hunterdon, Somerset, and Sussex Counties furnished less than 1 percent each.

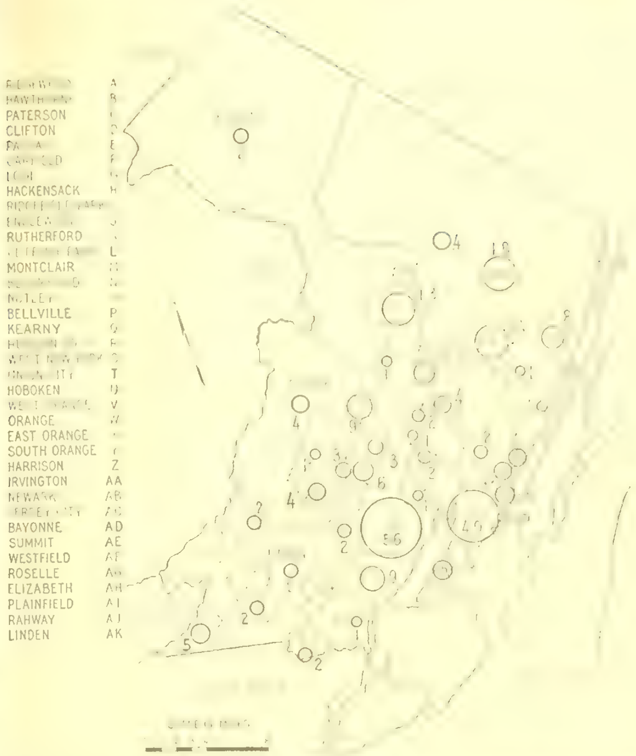


FIGURE 8.—AREAS SERVED BY FIFTEEN HUDSON AND DELAWARE RIVER CROSSINGS.

TRAFFIC FROM PRINCIPAL CITIES OF NEW JERSEY TO STATE OUTLETS STUDIED

The two chief factors which determined the route followed by traffic between outside States and certain New Jersey cities, by way of the principal Hudson and Delaware River crossings, were the proximity of the crossing to the city and the general nature and direction of the highways which connected them. The flow of average daily traffic to and from selected cities, shown in table 2, distinctly indicates this tendency. Figures for the 8 cities which have the greatest amount of traffic by way of the Hudson and Delaware River crossings here considered, are arranged in the general order of their location. The first 4 cities are in the Hudson River area, the next 3 on the Delaware, and the last on the Atlantic seaboard in the southern part of the State. Within the Hudson and Delaware River groups, the cities are arranged from north to south, Paterson and Hackensack being north of Jersey City and Newark, and Phillipsburg, Trenton, and Camden at about equal intervals from north to south on the Delaware, while Atlantic City is across the State southeast of Camden.

The Holland Tunnel and the George Washington Bridge are approximately the same distance from Paterson, but the highway to the bridge is much more direct. Hence almost half the Paterson traffic by way of Hudson and Delaware River crossings passed over the George Washington Bridge and something more than a third through the Holland Tunnel, which traffic, together with the small amount crossing on the Alpine-Yonkers Ferry, accounted for about seven-eighths of the total. Hackensack, on the other hand, which is about twice as far from the Holland Tunnel as from the George Washington Bridge, and is connected with both by equally good roads, received more than three-quarters of its river crossing traffic over the George Washington Bridge and about one-fifth through the Holland Tunnel.

Table 1.—*Daily average traffic using Hudson and Delaware River crossings analyzed by origin or destination*

Origin or destination	Daily average number of vehicles	Percent of total traffic	Origin or destination	Daily average number of vehicles	Percent of total traffic
Total	[1]24,277	100.0	Union County:		
			Elizabeth	1,179	0.9
Through traffic	20,282	16.3	Linden	132	.1
New Jersey traffic	103,995	83.7	Plainfield	565	.5
			Rahway	198	.2
Sussex County, total	298	.2	Roselle	79	(1)
			Summit	215	.2
Passaic County:			Westfield	208	.2
Clifton	167	.1	Other Union County	297	.2
Hawthorne	41	(1)			
Passaic	830	.7	Total	2,873	2.3
Paterson	1,622	1.3			
Other Passaic County	234	[2].2	Middlesex County:		
			Carteret	43	(1)
Total	2,894	2.3	New Brunswick	644	.5
			Perth Amboy	279	.2
			South River	49	(1)
Bergen County:			Other Middlesex County	497	[2].5
Cliffside Park	117	.1			
Englewood	933	.8	Total	1,512	1.2
Garfield	86	(1)			
Hackensack	1,735	1.4	Mercer County:		
Lodi	68	(1)	Trenton	12,192	9.8
Ridgefield Park	97	.1	Other Mercer County	864	.7
Ridgewood	489	.4			
Rutherford	498	.4	Total	13,056	10.5
Other Bergen County	2,163	[2]1.8			
			Monmouth County:		
Total	6,186	5.0	Asbury Park	715	.6
			Long Branch	191	.1
Warren County:			Red Bank	212	.2
Phillipsburg	12,085	9.7	Other Monmouth County	896	.7
Other Warren County	2,808	2.3			
			Total	2,014	1.6
Total	14,893	12.0			
			Burlington County:		
Morris County:			Burlington	657	.5
Dover	209	.2	Other Burlington County	3,749	3.0
Morristown	443	.4			
Other Morris County	748	.6	Total	4,406	3.5
Total	1,400	1.2	Ocean County, total	1,174	.9
Essex County:			Camden County:		
Belleville	189	.1	Camden	10,641	8.6
Bloomfield	330	.3	Collingswood	1,032	.8
East Orange	755	.6	Gloucester	607	.5
Irvington	224	.2	Other Camden County	5,215	4.2
Montclair	1,108	.9			
Newark	6,926	5.6	Total	17,495	14.1
Nutley	196	.2			
Orange	382	.3			
South Orange	490	.4			
West Orange	188	.1			
Other Essex County	551	.4	Gloucester County, total	4,024	3.2
Total	11,342	9.1	Atlantic County:		
			Atlantic City	6,396	5.1
Hudson County:			Pleasantville	74	(1)
Bayonne	665	.5	Other Atlantic County	1,530	[2]1.3
Harrison	136	.1			
Hoboken	609	.5	Total	8,000	6.4
Jersey City	5,035	4.0			
Kearny	211	.2	Salem County, total	959	.8
Union City	456	.4			
West New York	460	.4	Cumberland County:		
Other Hudson County	194	.2	Bridgeton	442	.4
			Millville	238	.2
Total	7,766	6.3	Other Cumberland County	611	.5
Hunterdon County, total	693	.6	Total	1,291	1.1
Somerset County, total	375	.3	Cape May County, total	1,344	1.1

[1] Less than 0.1 percent.

[2] Includes cities for which traffic was less than 0.1 percent.

Since the Holland Tunnel emerges in Jersey City, it is not surprising to find that 80 percent of the Jersey City river-crossing traffic passes through the tunnel, and about 13 percent over the George Washington Bridge, which is the second nearest principal crossing. Newark's nearest river crossing is also the Holland Tunnel and is connected with it by highly improved roads, with the result that 74 percent of its traffic is through the tunnel and 11 percent by way of the more distant George Washington Bridge. Hackensack is relatively near the George Washington Bridge and distant from the Holland Tunnel while the reverse is true of distances from Newark to the crossings. In both cases the percentages of traffic using the near and far crossings are about the same. Each city is also about the same distance from its next most important crossing, but almost twice as great a part of Hackensack's total traffic came from this secondary source. The greater importance of Newark as an industrial and commercial center, as well as its more direct accessibility to the principal crossings on the Delaware River, may explain a more general dispersion of its traffic with outside States than was found in the case of any other of the principal cities. Approximately half of Newark's daily traffic from river crossings other than the Holland Tunnel, came over the Hudson and the other half came over Delaware River crossings.

In marked contrast, the river-crossing traffic of Phillipsburg was confined almost exclusively to the Phillipsburg-Easton Bridge. Phillipsburg is not one of the larger cities of New Jersey, its population in 1930 being only 19,255. Its situation directly across the Delaware from Easton, Pa., which is about twice as large, and within 20 miles of Bethlehem and Allentown, Pa., both of which are of considerable importance industrially, accounts for an interchange of traffic over this principal river crossing similar to the shuttle-flow of traffic within the boundaries of a large city. On this account it is necessary to discount considerably the apparent importance of Phillipsburg as the point of origin or destination of a volume of river-crossing traffic which was exceeded only by similar traffic at Trenton. The traffic at Trenton is over its two important bridges, with 13 other crossings contributing small amounts.

As already indicated, the daily river-crossing traffic which originated or terminated at Trenton, averaging 12,192 cars a day, was greater than that of any other New Jersey city. Although Trenton is exceeded in population by Paterson, Newark, and Jersey City, it enjoys a unique position in being of historical interest, the State capital, an important industrial city, and it is at the head of tidewater navigation on the Delaware River. All of these factors contributed in varying proportion to its out-of-State traffic. Ninety-three percent of this traffic either entered or left the city by way of its two bridges across the Delaware, about 3 percent crossed the Hudson, and the remaining 4 percent used the other 10 Delaware River crossings.

As an important manufacturing and shipbuilding center directly across the Delaware from Philadelphia, and within the metropolitan area of Philadelphia, Camden is one of the most important New Jersey terminals of interstate highway traffic. More than 94 percent of Camden's traffic which came by way of Hudson or Delaware River crossings entered or left the city by one or another of the 3 principal crossings between Camden and Philadelphia; 73 percent of such traffic used the Delaware River Bridge; and the traffic from the Pennsylvania and Reading Railroad ferries amounted to more than 10 percent each. Almost half the remaining Camden traffic crossed the Palmyra-Philadelphia Bridge in going to or coming from Philadelphia, with the other 3 percent unevenly distributed among all other principal crossings.

Atlantic City is a middle Atlantic beach resort of widespread popularity. The daily ebb and flow of tourist traffic combined with the supplementary commercial traffic, a large part of which came from Phila-

TABLE 2.—*Daily average traffic which originates or terminates in designated cities using each principal Hudson or Delaware R[illegible] crossing*

Crossing	Paterson		Hackensack		Jersey City		Newark		Phillipsburg		Trenton		Camden		Atlantic City	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Fifteen crossings, total	1,622	100.0	1,735	100.0	5,035	100.0	6,926	100.0	12,085	100.0	12,192	100.0	10,641	100.0	[illegible]	[illegible]
Hudson River crossings:																
Holland Tunnel	582	35.9	332	19.1	4,048	80.4	5,131	74.1	23	.2	292	2.4	97	.9	258	4.0
George Washington Bridge	803	49.5	1,314	75.8	651	12.9	781	11.3	4	(1)	56	.5	24	.2	44	[illegible]
Alpine-Yonkers Ferry	23	1.4	30	1.7	24	.5	36	.5	(2)	(1)	3	(1)	1	(1)	2	[illegible]
Total	1,408	86.8	1,676	96.6	4,723	93.8	5,948	85.9	27	.2	351	2.9	122	1.1	304	4.8
Delaware River crossings:																
Columbia-Portland Bridge	9	.6	3	.2	6	.1	15	.2	2	(1)	2	(1)	1	(1)	[illegible]	[illegible]
Delaware-Portland Bridge	63	3.9	11	.6	78	1.5	185	2.7	55	.4	71	.6	15	.1	[illegible]	[illegible]
Phillipsburg-Easton Bridge	73	4.5	13	.7	74	1.5	246	3.6	11,997	99.3	78	.6	8	.1	8	[illegible]
Trenton-Langhorne Bridge	28	1.7	10	.6	60	1.2	220	3.2	1	(1)	3,347	27.4	6	(1)	[illegible]	[illegible]
Trenton-Morrisville Bridge	26	1.6	13	.7	58	1.2	215	3.1	2	(1)	8,018	66.0	40	.4	12	.2
Burlington-Bristol Bridge	1	(1)	------	------	1	(1)	5	(1)	(2)	(1)	21	.2	61	.6	[illegible]	[illegible]
Palmyra-Philadelphia Bridge	2	.1	1	(1)	3	(1)	5	(1)	(2)	(1)	24	.2	288	2.7	754	11.8
Camden-Philadelphia Bridge	5	.3	5	.3	17	.3	44	.6	1	(1)	207	1.7	7,815	73.4	4,577	71.6
Camden-Philadelphia Ferry (Pennsylvania Railroad)	----	----	(2)	(1)	1	(1)	3	(1)			11	.1	1,082	10.2	46	.7
Camden-Philadelphia Ferry (Reading Railroad)	1	(1)	------	------	1	(1)	4	(1)	----	----	10	.1	1,123	10.6	226	3.5
Bridgeport-Chester Ferry	2	.1	------	------	5	.1	8	.1	----	----	10	.1	53	.5	142	2.2
Pennsville-New Castle Ferry	4	.3	3	.2	8	.2	28	.4	----	----	12	.1	27	.3	285	4.5
Total	214	13.2	59	3.4	312	6.2	978	14.1	12,058	99.8	11,841	97.1	10,519	98.9	6,092	95.2

[1] Less than 0.1 percent.

[2] Less than 1 vehicle a day.

delphia, explains the large volume of daily river-crossing traffic to and from this city. Almost 72 percent of this traffic entered or left New Jersey by the Delaware River Bridge at Camden, and about 12 percent by the Palmyra-Philadelphia Bridge. The Pennsville-New Castle ferry, the southernmost Delaware River crossing, carried 4.5 percent, and the Holland Tunnel carried 4 percent of such traffic. The Reading Railroad ferry at Camden and the Bridgeport-Chester ferry in Gloucester County, were the only other crossings carrying more than 1 percent of the Atlantic City total traffic, with all other crossings contributing something to its traffic.

CHARACTERISTICS OF TRUCK AND BUS TRAFFIC DETERMINED FROM SAMPLE COUNT

Trucks and busses were stopped and detailed information relating to their movement was recorded at 78 representative points throughout the State and at regular intervals during the year. Although information regarding only a part of total traffic was obtained, these sample data represented an average cross-section of truck and bus traffic in New Jersey at the time of the survey. Occasionally all the required information was not obtained and it may be found that figures for a given item of information in one tabulation differ slightly from those for the same item in another.

The following data relate to the selected sample of traffic passing over New Jersey highways and not to the actual number of individual vehicles of a certain type. For example, a bus making several trips a day would be counted as many times as it passed an occupied survey station. Statements regarding the proportions of various classes of vehicles refer to the sample of traffic under consideration, without taking account of the number of times an individual vehicle may be included therein. Thus, while it is correct to say that 30 percent of New Jersey bus traffic consists of 1929 model busses, this does not mean that 30 percent of the busses in New Jersey are 1929 models.

In the total sample, comprising 267,025 vehicles, there were 239,368 trucks and 27,657 busses, or almost 9 times as many trucks as busses. Approximately 53 percent of the total number of trucks and busses operated in the northeast section of the State adjacent to New York City, a large part of this section being included within the New York metropolitan area in New Jersey. The southwest section of the State, including the cities of Trenton and Camden and other districts in the neighborhood of Philadelphia, was traversed by about 22 percent of the total truck and bus traffic of the State, and the northwest and southeast sections, by about 10 and 15 percent, respectively.

Of the total sample of truck and bus traffic throughout the State, trucks represented 89.6 percent and busses 10.4 percent. In the northwest section, consisting of Sussex, Warren, Hunterdon and Somerset Counties, 91.6 percent of the combined traffic was by trucks, indicating a relatively greater transportation of commodities than passengers. On the other hand, in the southwest section which is traversed by a large part of the tourist traffic to New Jersey beach resorts, busses represented 11.8 percent of the combined truck and bus traffic of the section.

TRUCKS CLASSIFIED ACCORDING TO OWNERSHIP

Slightly more than half the trucks operating over New Jersey highways were owned by business organizations located in cities or towns of 2,500 inhabitants or more. Private individuals living in such urban areas owned 39 out of every 100 observed trucks. Trucks owned by persons living in rural districts or on farms represented less than 10 percent of the truck traffic, and trucks owned by governmental agencies represented only a little more than 1 percent. Table 3 shows the classification of trucks observed according to ownership.

The greater part of the northeast section of New Jersey is included within the New York metropolitan area. In this section trucks owned by city companies constituted a higher percentage than in any other part of the State. City companies owned about 57 out of each 100 trucks operating in this area. The companies were principally manufacturing and business organizations located within this district, but many trucks owned by New York firms as well as a smaller number owned

Table 3.—*Trucks observed on New Jersey highways, classified according to ownership*

Class of ownership	Number	Percent
Total, all classes	239, 368	100. 0
Farm ownership	22, 5[illegible]	9. 4
Total city ownership	214, 228	89. 5
Company	121, 463	50. 7
Private	92, 765	38. 8
Government ownership	2, 625	1. 1

by establishments in Philadelphia and other cities were observed. Individuals living in northeastern New Jersey cities owned 36 percent of the trucks in the traffic sample, and were principally engaged in small businesses. Farm-owned trucks constituted about 7 percent of trucks operating in this area which has fewer farms than any other section of the State.

The northwest section of the State is largely a farming district, and its percentage of farm-owned trucks was almost twice as great as that of the northeast section. But even in this more rural district, 86 percent of observed trucks were city-owned.

The proportion of city-owned trucks operating in southeastern New Jersey was only slightly higher than that in the northwest section of the State, but there was a preponderance of company-owned trucks, which comprised almost 48 percent of truck traffic in this section. About 40 percent were privately owned. Although there are many business and industrial establishments in this district, the prevalence of company-owned trucks on its highways was partly due to the operation of trucks owned by large supply houses in New York City, Philadelphia, Camden, and other cities engaged in trucking to coast resorts. The farming industry is of considerable importance in this district and 11 percent of the trucks operating in this section were farm-owned.

The extensive rural areas in Burlington, Gloucester, and Salem Counties accounted for a large part of the 14 out of each 100 trucks operating in southwestern New Jersey which were farm-owned. This section had the smallest proportion of city-owned trucks, 84 percent being of this class, and these were almost evenly divided between company and private ownership.

OWNER-OPERATED TRUCKS MAKE UP GREATER PORTION OF TRUCK TRAFFIC

There are three principal classes of truck operation, if the small number of Government-operated trucks is included in the owner-operated class. The owner-operated class includes those trucks, whether of company, private, farm or Government ownership, which are operated by their owners either personally or by their employees in the business of the owner. Trucks operated as contract haulers are engaged in the business of trucking for others for hire, trips being made when and where desired at rates agreed upon by the contracting parties. Trucks operated as common carriers follow established routes between definite points, operate on a regular schedule, and charge standard published rates. Throughout the entire State, owner-operated trucks constituted 79 percent of the sample count, contract-hauler trucks 17.7 percent, common-carrier trucks 2.2 percent, and Government-operated trucks 1.1 percent.

Of the total volume of truck traffic included in the sample, almost two-thirds is State and a little more than one-third interstate traffic. This means that about 66 out of each 100 trucks have both their origin and destination within the State. In the northwest section of the State 42 percent of trucks were found to be operating in interstate traffic. This section of New Jersey lies in the path of traffic en route from central and western Pennsylvania to points in New Jersey, upper New York, or the New England States, and truck traffic between New York City and points in northern Pennsylvania, or beyond, also passes through this section. Only about 16 percent of trucks operating in the southeast section of New Jersey are engaged in interstate traffic.

Another analysis of the figures relating to trucks engaged in State and interstate traffic, according to class of truck operation, is given in table 4, and is also presented graphically in figure 9. In general, contract-hauler and common-carrier trucks operated more frequently in interstate traffic than did owner-operated trucks. This classification shows that 72.5 percent of owner-operated trucks were engaged in State traffic and that only 27.5 percent went outside of New Jersey. Among both contract-hauler and common-carrier trucks, only about one-third were engaged in State and two-thirds in interstate operation. Of the few Government-operated trucks recorded, 90 percent travel within the State and 10 percent between States.

Table 4.—*State and interstate traffic by class of truck operation*

Class of operation	Total traffic		State traffic		Interstate traffic	
	Number of trucks	Percent [1]	Number of trucks	Percent [2]	Number of trucks	Percent [2]
All classes, total	239, 368	100. 0	156, 732	65. 5	82, 636	34. 5
Owner operator	189, 159	79. 0	137, 152	72. 5	52, 007	27. 5
Contract hauler	42, 278	17. 7	15, 474	36. 6	26, 804	63. 4
Common carrier	5, 273	2. 2	1, 715	32. 5	3, 558	67. 5
Government operation	2, 658	1. 1	2, 391	90. 0	267	10. 0

[1] Percent of all classes of operation, total.
[2] Percent of total for each class of operation, respectively.

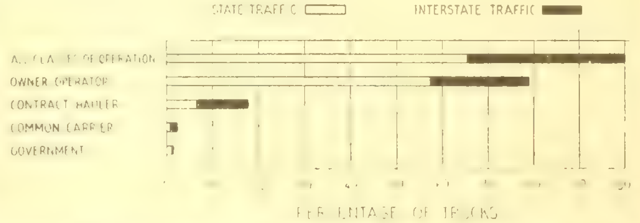


Figure 9.—Percentage Distribution of Trucks, by Class of Operation in State and Interstate Traffic.

TRUCKS CLASSIFIED ACCORDING TO COMMODITIES HAULED

Thirty-two percent of all trucks included in the New Jersey sample were running empty; 2.2 percent carried passengers; 65.7 percent carried commodities; and 0.1 percent had no load capacity, the latter group including chassis, tractors, or other vehicles without bodies designed for hauling loads. The loads carried by trucks were classified according to fixed commodity groups and the results are shown in table 5 and figure 10.

The loads of trucks classified according to type of operation are presented in table 6. Among trucks of the owner-operated class, 33 percent were found to be running empty, in contrast with about 30 percent of contract-hauler trucks, and only 12 percent of common-carrier trucks. Relatively more owner-operated trucks were found carrying passengers. It appears that there

Table 5.—*Nature of truck loads carried*

Nature of load	Number of trucks	Percentage of all trucks	Percentage by groups
All trucks, total	239,368	100.0	
No commodity or commodity not classified	82,328	34.4	100.0
Running empty	76,499	32.0	92.8
Carrying passengers	5,538	2.2	6.5
No load capacity	368	.1	.5
Loaded, commodity not classified	123	.1	.1
Commodity specified, total	157,040	65.6	100.0
Manufactured products, wholesale delivery, etc	87,437	36.4	55.7
Agricultural products	32,002	13.4	20.4
Retail delivery	17,595	7.4	11.2
Products of mines (coal, oil, etc.)	9,277	3.9	5.9
Household goods	5,156	2.2	3.3
Forest products (lumber, trees, shrubs, etc.)	4,073	1.7	2.6
State highway construction materials, etc	1,182	.5	.7
Valuables, mail, armored cars, etc	318	.1	.2

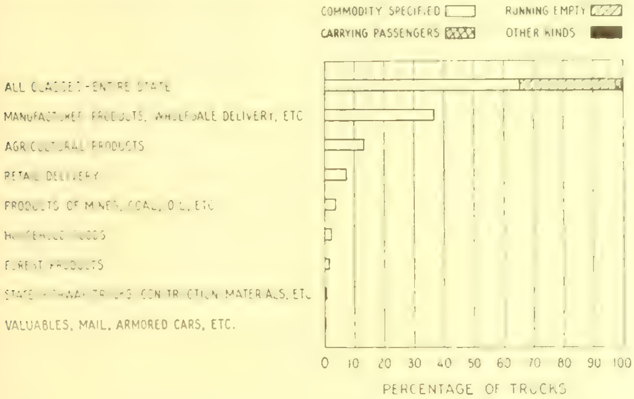


Figure 10.—Percentage Distribution of Trucks, by Nature of Load Carried.

Table 6.—*Nature of load carried by class of truck operation*

Nature of load	3 classes of operation		Owner operator		Contract hauler		Common carrier	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
All kinds, total	236,710	100.0	189,159	100.0	42,278	100.0	[illegible]	[illegible]
Running empty	76,034	32.1	62,840	33.2	12,569	29.7	[illegible]	11.9
Carrying passengers	5,006	2.1	4,831	2.6	158	.4	17	.3
No load capacity	354	.2	311	.2	43	.1		
Loaded, commodity not specified	101	(1)	90	(1)	11	(1)		--
Commodity specified total [3]	155,215	65.6	121,087	64.0	29,497	69.8	4,631	87.8
Manufactured products, wholesale delivery, etc	86,624	[2] 55.8	63,137	[2] 52.2	19,297	[2] 65.4	4,190	[2] 90.5
Agricultural products	31,462	[2] 20.3	26,117	[2] 21.6	5,118	[2] 17.4	227	[2] 4.9
Retail delivery	17,617	[2] 11.3	17,246	[2] 14.3	323	[2] 1.1	48	[2] 1.0
Products of mines, coal, oil, etc	9,094	[2] 5.9	7,853	[2] 6.5	1,162	[2] 3.9	79	[2] 1.7
Household goods	5,100	[2] 3.3	2,694	[2] 2.1	2,442	[2] 8.3	64	[2] 1.4
Forest products, lumber, trees, shrubs, etc	4,039	[2] 2.6	3,670	[2] 3.0	360	[2] 1.2	9	[2] .2
State highway construction materials, etc	982	[2] .6	414	[2] .3	558	[2] 1.9	10	[2] .2
Valuables, mail, armored cars etc	297	[2] .2	56	(1)	237	[2] .8	4	[2] .1

[1] Less than 1/10 of 1 percent

[2] Based on number of trucks for which commodity carried was specified

Table 7.—*Nature of return load by class of truck operation*

Nature of return load	3 classes of operation		Owner operator		Contract hauler		Common carrier	
	Number	*Percent* [1]	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
All kind, total	236,710	100.0	189,159	100.0	42,278	100.0	5,273	100.0
Returning empty	72,612	30.7	57,688	30.5	14,080	33.3	844	16.0
Not returning	6,743	2.8	5,277	2.8	1,466	3.5	--	--
Carrying passengers	1,035	.4	872	.5	67	.2	96	1.8
No load capacity	369	.2	327	.2	42	.1	--	--
Returning loaded, total [1]	155,951	65.9	124,995	66.0	26,623	62.9	4,333	82.2
Commodity not specified	142,430	[1] 91.3	114,327	[1] 91.5	24,336	[1] 91.4	3,767	[1] 86.9
Commodity specified	13,521	[1] 8.7	10,668	[1] 8.5	2,287	[1] 8.6	566	[1] 13.1

[1] Based on number of trucks returning loaded.

is less waste of truck capacity in common-carrier and contract-hauler operation than in owner operation. Owner-operated trucks carried a greater percentage of agricultural products, retail delivery, coal, oil, and forest products than either of the other two classes. In hauling these commodities the truck is usually loaded at a fixed point, deliveries are made, and the truck returns empty to the point of origin. In both contract and common-carrier hauling, on the other hand, trips are planned so as to have the truck loaded on both the outgoing and return trip whenever possible.

As shown in table 7, approximately 66 out of each 100 trucks were expected to bring back a return load; 31 were expected to return empty; 3 were not expected to return; and only 6 per 1,000 were expected to carry passengers, or had no load capacity.

CAPACITY OF TRUCKS STUDIED

Trucks observed in this survey were of many kinds and capacities, ranging from small roadsters of only a fraction of a ton capacity used for local light delivery to large trailer vans used for long-distance hauling. In order to reduce this great variety of sizes to a few comparable groups, trucks have been classified as light, medium, and heavy. Light trucks include all trucks of 1½ tons capacity and under; medium trucks include all trucks of capacities between 1½ and 5 tons; and heavy trucks include all trucks of 5 tons capacity and over. For the entire State, light trucks, including passenger cars used for delivery or other hauling, comprised 55.5 percent; trucks of medium capacity comprised 23.3 percent; and heavy trucks comprised 21.2 percent of the total.

It may be interesting to compare the capacities of trucks making up New Jersey traffic during 1932–33 with similar data compiled for other States during previous years. A survey of transportation on the State highway system of Ohio made in 1926, showed that 71.8 percent of all trucks were light capacity; 26 percent were medium capacity; and 2.2 percent were heavy capacity. The composition of New Jersey traffic is definitely affected by the large amount of heavy hauling to or from New York City and Philadelphia which lie at the termini of the principal traffic arteries of the State.

A survey of traffic on the Federal-aid highway system of 11 Western States was made during 1929–30 by the Bureau of Public Roads and the highway departments of the respective States. Nebraska, all the Mountain States except Montana, and the Pacific States were included in this survey. The classification of truck traffic of each of these States, according to the same capacity groups as those used for New Jersey, is presented in table 8.

A grouping of the truck capacities in New Jersey and the western States according to the percentage of farm and village ownership, as opposed to city ownership, indicates that the percentage of lighter trucks tends to increase with an increase in the percentage of farm and village ownership, while medium- and heavy-capacity trucks increase with an increase in city ownership, as shown in table 9. California stands alone as group 1, since it is the only one of the 11 western States for which the classification of trucks by ownership shows one-

Table 8.—*Percentage distribution of trucks in various States by capacity*

State	1½ tons and under	From 1½ to 5 tons	5 tons and over
	Percent	*Percent*	*Percent*
New Jersey, 1932-33	55.5	23.3	21.2
Ohio, 1926	71.8	26.0	2.2
11 western States, 1929-30	67.9	26.3	5.8
Arizona	64.7	31.8	3.5
California	58.6	30.2	11.2
Colorado	73.5	20.7	5.8
Idaho	72.5	20.8	6.7
Nebraska	74.4	24.1	1.5
New Mexico	79.8	18.7	1.5
Nevada	66.1	25.8	8.1
Oregon	63.1	30.9	6.0
Utah	77.2	20.1	2.7
Washington	64.6	27.0	8.4
Wyoming	78.3	19.9	1.8

third farm and village owned and two-thirds city owned. The second group is made up of Oregon, Utah, Arizona, Washington, Idaho, and Colorado, the relative percentages of ownership varying from about 40 to 60 percent farm and village ownership, with an average of 53.7 percent. The third group consists of Nebraska, New Mexico, Nevada, and Wyoming, for which the percentages of farm and village ownership range from 60 to 80 percent, with an average of 70.4 percent.

Table 9.—*Percentage of light and medium and heavy trucks compared with percentages of city and farm and village ownership*

	Average percentage of ownership		Average percentage of trucks	
	Farm and village	City	Light	Medium and heavy
New Jersey	9.5	90.5	55.5	45.5
Western States:				
Group 1	33.9	66.1	58.6	41.4
Group 2	53.7	46.3	69.3	30.7
Group 3	70.4	29.6	74.7	25.3

ONE-HALF OF TRUCKS MAKE ONE OR MORE TRIPS A DAY

The frequency of trips made by trucks over New Jersey highways ranged from a maximum of more than 10 trips a day to a minimum of only one trip at intervals of more than 30 days, as shown in table 10. Exactly one-half of the trucks made one trip or more a day, while the other half made trips at longer intervals. Of each thousand trucks observed 413 made one trip a day, 79 made from 2 to 5 trips a day, 7 made from 6 to 10 trips a day, and only 1 made more than 10 trips a day.

Table 11 shows the frequency of truck operation by classes of operation.

Table 10.—*Frequency of trips by class of truck operation*

Trip frequency group	3 classes of operation		Owner operator		Contract hauler		Common carrier	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
All frequencies, total	236,710	100.0	189,159	100.0	42,278	100.0	5,273	100.0
More than 10 trips a day	251	.1	109	.1	133	.3	9	.2
6 to 10 trips a day	1,685	.7	1,157	.6	518	1.2	10	.2
2 to 5 trips a day	18,598	7.9	16,049	8.5	2,353	5.6	196	3.7
One trip a day	97,681	41.3	76,725	40.6	17,754	42.0	3,202	60.7
One trip every 2 days	33,354	14.1	25,418	13.4	7,037	16.6	899	17.0
One trip every 3 days	36,352	15.4	28,895	15.3	6,879	16.3	578	11.0
One trip every 4 days	1,197	.5	1,023	.5	160	.4	14	.3
One trip every 5 days	479	.2	386	.2	84	.2	9	.2
One trip every 6 days	780	.3	674	.4	104	.2	2	(1)
One trip every 7 days	38,203	16.1	32,108	17.0	5,784	13.7	311	5.9
One trip every 8 to 14 days	4,505	1.9	3,676	1.9	802	1.9	27	.5
One trip every 15 to 30 days	3,524	1.5	2,852	1.5	656	1.6	16	.3
Trips more than 30 days apart	101	(1)	87	(1)	14	(1)		

[1] Less than 1/10 of 1 percent

Table 11.—*Frequency of truck operation by classes of operation*

Class and frequency	Number of trucks	Percent	Average trip frequency
			Days
3 classes, total	236,710	100.0	3.03
More than 1 trip a day	20,534	8.7	.39
1 trip a day	97,681	41.3	1.00
Less than 1 trip a day	118,495	50.0	5.17
Owner operators, total	189,159	100.0	3.09
More than 1 trip a day	17,315	9.2	.40
1 trip a day	76,725	40.6	1.00
Less than 1 trip a day	95,119	50.2	5.27
Contract haulers, total	42,278	100.0	2.95
More than 1 trip a day	3,004	7.1	.34
1 trip a day	17,754	42.0	1.00
Less than 1 trip a day	21,520	50.9	4.91
Common carriers, total	5,273	100.0	1.87
More than 1 trip a day	215	4.1	.35
1 trip a day	3,202	60.7	1.00
Less than 1 trip a day	1,856	35.2	3.54

These same figures are presented in a different arrangement in table 12 for the purpose of showing the distribution of trucks in the respective trip frequency of groups among the various classes of operators. Nearly 80 percent of all trucks were operated in the business of owners; 17.4 percent were contract haulers; and only 2.8 percent were common carriers. The average trip frequency of these groups was 3.09 days, 2.95 days and 1.87 days, respectively, which means that common carriers as a class made the most frequent trips, contract haulers the next most frequent, and owner operators made the least frequent trips. Among trucks that made more than one trip a day, there was a considerably greater proportion of owner operators, 84.4 percent being of this class, but the average trip frequency for owner operators was less than that of either contract haulers or common carriers. Of the one-trip-a-day frequency group, owner operators represent the smallest percentage and there is a greater proportion of common carriers in this group than in any other group. Contract haulers appear in about the same proportion in both the one-trip-a-day and the less-than-one-trip-a-day groups. In the latter group, common carriers make trips more frequently and owner operators less frequently than any other class.

Table 12.—*Average trip frequency by class of truck operation*

Frequency and class	Number of trucks	Percent	Average trip frequency
			Days
All trip frequencies, 3 classes	236,710	100.0	3.03
Owner operator class	189,159	79.8	3.09
Contract hauler class	42,278	17.4	2.95
Common carrier class	5,273	2.8	1.87
More than 1 trip a day, 3 classes	20,534	100.0	.39
Owner operator class	17,315	84.4	.40
Contract hauler class	3,004	14.3	.34
Common carrier class	215	1.3	.35
1 trip a day, 3 classes	97,681	100.0	1.00
Owner operator class	76,725	78.3	1.00
Contract hauler class	17,754	17.6	1.00
Common carrier class	3,202	4.1	1.00
Less than 1 trip a day, 3 classes	118,495	100.0	5.17
Owner operator class	95,119	80.3	5.27
Contract hauler class	21,520	17.7	4.91
Common carrier class	1,856	2.0	3.54

MANY TYPES OF BODIES FOUND ON TRUCKS

A great variety of truck bodies is now seen upon our highways. Trucks are being adapted to many types of hauling requiring special equipment, of which the tank truck and the ready-mixed-concrete truck are familiar types. In the total volume of truck traffic in New Jersey, however, 7 out of every 8 vehicles used as trucks have a standard covered, stake, or open body. The covered truck was observed more frequently than any other type and represented 46.5 percent of all New Jersey truck traffic. Stake- and open- body trucks were in approximately equal proportions, comprising 21.4 percent and 19.8 percent of all trucks, respectively. Among the types which were found less frequently the truck with trailer appeared most often, about 5 percent being of this class. Tank trucks constituted 3.2 percent of New Jersey truck traffic and were in large part serving the extensive refining industry of the State. Trucks with unusual types of body occur less than 3 times in each 100 trucks, and one in every 100 vehicles classified as trucks was a passenger car used as a truck, often for retail delivery or other light hauling. Only 3 trucks per 1,000 had platform bodies. Table 13 shows the data on truck bodies in detail.

TABLE 13.—*Truck body types*

Type of body	Number of trucks	Percent of total
Covered	111,376	48.7
Stake	51,078	22.4
Open	47,439	20.8
Tank	7,714	3.4
Special body	6,806	3.0
Passenger cars (used to haul commodities)	2,278	1.0
Platform	764	.4
Refrigerator	307	.1
None (tractor without trailer)	290	.1
Bus (used to haul commodities)	188	.1
Total	228,240	100.0

ONLY 5 PERCENT OF TRUCKS HAULED TRAILERS

The extent to which trailers are used is shown in table 14. Passenger-car trailers are not included and no distinction is made between semitrailers and full trailers. Trailers are of relatively minor importance since 95 percent of all trucks operate without trailers. Only 1 truck in 20,000 hauled more than 1 trailer.

TABLE 14.—*Number of trailers observed*

Class	Number of trucks	Percent of total
All trucks, total	239,368	100.0
Without trailers	228,240	[illegible]
With 1 trailer	11,117	[illegible]
With 2 trailers	11	[illegible]

[1] Less than 1/10 of 1 percent.

80 PERCENT OF TRUCKS FOUND TO BE NOT OVER 5 YEARS OLD

The age of trucks operating in New Jersey at the time of this survey is shown in table 15 and figure 11. Since the survey was in progress from August 1932 to August 1933 all trucks of the 1933 model are classified in the first age group as less than 1 year old. A 1932 model purchased in December of that year was not a year old at the latest date of this survey, but for the sake of simplicity and because the actual date of purchase of trucks was not known, all 1932 models were classified as 1 year old, and so on, for each of the other age groups. According to this classification, the median age, or an age so chosen that half the trucks are above and half below that age, is 3 years, 53 percent of all trucks being not more than 3 years old. The average life of a truck is probably about 5 years, although trucks depreciate more or less rapidly according to the nature of their construction and the kind of use to which they are put. Eighty percent of the trucks on New Jersey highways were not more than 5 years old. Ninety-nine percent of all trucks were not more than 12 years old, but a scattering of old-timers was observed, 4 trucks per 100,000 of those recorded being models of years prior to 1910.

TABLE 15.—*Age of trucks*

Age	Number of trucks	Percent of total	Cumulative percentage
Less than 1 year (1933 model)	[illegible]	[illegible]	[illegible]
1 year (1932 model)	[illegible]	14.1	[illegible]
2 years (1931 model)	[illegible]	[illegible]	36.2
3 years (1930 model)	40,530	16.9	[illegible]
4 years (1929 model)	43,012	[illegible]	71.1
5 years (1928 model)	22,947	[illegible]	[illegible]
6 years (1927 model)	15,396	[illegible]	[illegible]
7 years (1926 model)	11,965	5.0	[illegible]
8 years (1925 model)	6,979	2.9	95.1
9 years (1924 model)	4,115	1.7	96.8
10 years (1923 model)	[illegible]	1.1	[illegible]
11 and 12 years (1922–1921 models)	2,519	1.1	99.0
13 to 15 years (1920–1918 models)	1,639	.7	99.7
16 to 20 years (1917–1913 models)	612	.3	100.0
More than 20 years (earlier models)	[1] 35	[2]	
All ages, total	239,368	100.0	

[1] 10 of this number were models of years prior to 1910.
[2] Less than 1/10 of 1 percent.

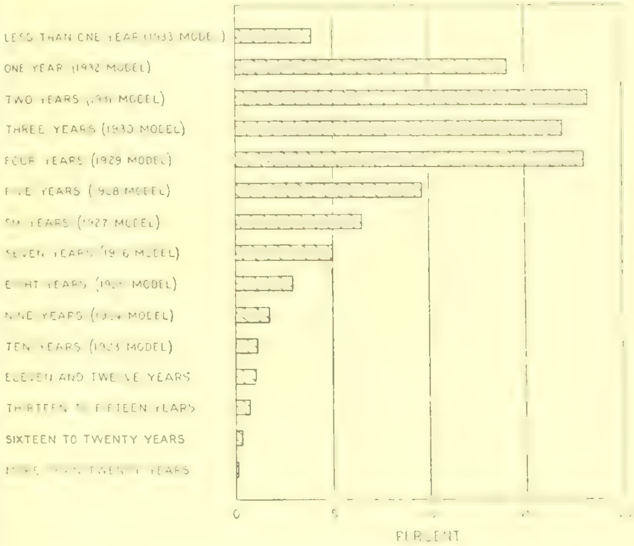


FIGURE 11.—PERCENTAGE DISTRIBUTION OF TRUCKS IN OPERATION IN 1932–33 BY AGE GROUPS.

NEEDED RESEARCH ON FLEXIBLE-TYPE BITUMINOUS ROADS[1]

By **E. F. KELLEY**, Chief, Division of Tests, Bureau of Public Roads

IN INTRODUCING a discussion of flexible-type bituminous roads it will be well to define first what is meant by the word "flexible." It is a term which is quite generally applied to road surfaces, without much regard to its exact meaning, to designate those types which have little or no flexural strength, as contrasted with the truly rigid types which have high flexural strength. Thus, a flexible-type surface may not be flexible in the true sense of the word but all surfaces of this type have the common characteristic of low beam-strength. Also, they have the ability, in varying degree, to adjust themselves to minor settlements without structural failure.

The function of a bituminous road surface of the flexible type is to carry the wheel loads of vehicles without failure of the bituminous wearing course, the base course, or the subgrade. These three component parts of a flexible type bituminous road are interdependent and the characteristics of each affect the performance of the whole.

MORE SATISFACTORY TESTS NEEDED FOR IDENTIFICATION OF BITUMINOUS MATERIALS

Subgrades.—During recent years great progress has been made in increasing our knowledge of soils and their use as subgrade materials. We have learned to differentiate with some precision between good subgrade soils and poor ones; we have learned something regarding frost action and the means for eliminating its detrimental effects; we are increasing our knowledge of the consolidation of fill materials; and, finally, we have learned much regarding the stabilization of soils, particularly by means of suitable combinations of soil materials. But soil science is still in its infancy and, in the larger sense, the research that is needed is barely under way. The possibilities of stabilization with admixtures of chemicals or bituminous materials are particularly promising.

Base courses.—What has been said with respect to subgrades is also generally applicable to base courses. Our knowledge of bases of the macadam type, which depend primarily on internal friction for stability, is largely the result of experience. But soil science, coupled with experience, has greatly extended our knowledge of the essential characteristics of such base-course materials as sand-clay, gravel, limerock, and caliche. Here, also, the possibilities of stabilization with other than soil materials merit careful investigation.

Bituminous wearing courses.—In bituminous wearing courses, as in subgrades and base courses, stability or resistance to lateral displacement is an essential characteristic. But here we have a part of the road structure in which other qualities are of increased importance. The wearing course is subjected to the direct action of traffic and weather. Adequate strength and durability of the mineral aggregate and durability of the bituminous binder are necessary.

Numerous investigations have developed valuable information regarding stability as affected by character and grading of mineral aggregate and character and quantity of bituminous binder. Further research on these materials is needed. The development of a test for stability, preferably a simple one, that will simulate the action of a paving mixture under wheel loads, would go far toward solving some of the questions that now confront the engineer.

With respect to mineral aggregates, much has already been learned regarding strength characteristics and durability, but further work remains to be done. The relative affinity of aggregates for water and for bitumen is a characteristic that has not yet received the attention it deserves.

The present question of pressing importance in the field of bituminous surfacing has to do with the durability of the bituminous material itself. The large programs of highway construction, involving a large mileage of the low-cost type, have focused attention on a problem that previously has not been of great concern.

It is known that some bituminous materials lack durability or resistance to weathering. In the road surface they soon lose their cementing properties and the friable mixture which results may fail rapidly under traffic. In the absence of a definite method of differentiating between good and poor materials, specification writers are now requiring compliance with test requirements which are primarily for the identification of the source of the material. While these requirements may exclude certain poor materials, they are so little a measure of quality that they may also exclude materials that are known to be satisfactory. There appears to be needed an accelerated weathering test which can be made in a few hours. Research on suitable test methods is under way and should be continued.

Inference should not be made that bituminous materials of low resistance to weathering are necessarily valueless. With a full realization of their limitations, economic considerations may sometimes dictate their use in preference to more expensive materials. It may be possible to use them advantageously in mixtures that are protected by weather-resistant wearing courses. However, we must have some means of identifying them so that they may not be used improperly.

RATIONAL METHOD FOR DESIGNING FLEXIBLE SURFACES NEEDED

The road structure.—We have learned much, both from practical experience and from research, regarding the design of the component parts of the flexible-type road. Concerning the design of the road structure as a whole we know very little except what has been taught us by experience. For roads of the rigid type the analyses of Westergaard, supplemented by research, have given us the basis for a rational theory of design applicable to concrete pavements. For roads of the flexible type no rational method of design exists and rule-of-thumb methods are still used. Attempts have been made to develop a rational theory but these are based on questionable assumptions of such far-reaching importance that they can scarcely be accepted without verification by further research.

From the structural standpoint, the function of a pavement of the flexible type is to distribute the wheel load to the subgrade in such manner that the intensity of pressure will cause neither permanent nor elastic deformations of the soil sufficient in magnitude to produce failure of the pavement surface. The rational design of a pavement to perform this function requires a knowledge of the mechanics of load support. The characteristics of the applied loads, the magnitude and distribution of the forces of subgrade reaction, and the physical behavior of the pavement under these two sets of forces must be determined.

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[1] Presented before Highway Research Board on Dec. 7, 1934, as an introduction to a symposium on flexible-type bituminous roads.

This problem is of outstanding importance. Its complicated nature is indicated by the following brief analysis of some of its details.

The more important variables which must be considered are:

1. The magnitude of the load.
2. The position of the load on the pavement.
3. The area of load application and the distribution of pressure over the loaded area.
4. The time duration of loading.
5. The thickness of the pavement (base course plus wearing course).
6. The internal stability of both base and wearing courses.
7. The distribution of pressure on the subgrade.
8. The supporting power of the subgrade.

The vehicle load, which is important in the design of any pavement, is known to be the maximum wheel load. Within resasonable limits the maximum wheel load likely to operate over a given road can be determined. This, of course, is the maximum static load and must be considered since heavy vehicles may stop on the highway surface for considerable periods of time. The impact forces produced by the wheels of moving vehicles must also be considered since these are greater than the forces due to static wheel loads and may exceed them many times. Researches extending back over the past 15 years make it possible to predict, with a fair degree of accuracy, the magnitude and frequency of the impact reactions that may be expected for specific conditions of wheel load, tire equipment, vehicle speed and road roughness.

The position of the applied load on the pavement is also a factor which must be considered. A load applied near the free edge of the pavement will have a different effect from that of one applied in the interior portion where continuity exists. Rational design requires that there be equal resistance to load in all parts of the structure and this can be obtained only by systematic study of the mechanics of pavement action.

The area of load application and the distribution of pressure over the loaded area are two separate though related factors. The effect of the area of load application has been quite thoroughly investigated with respect to the design of concrete pavement slabs. It seems quite probable that not only the size but the shape of the loaded area may be an even more important factor in its relation to flexible pavements. The effect of variations in intensity of pressure over the loaded area is also a detail which must be investigated.

Between standing or static loads, slowly rolling loads, and suddenly applied impact forces there is a difference in time duration which is probably quite important in flexible-type pavements. For example, under certain conditions it is very probable that a standing vehicle of given wheel load may subject the pavement to a more severe condition than will the same vehicle moving at speed and producing impact reactions greatly exceeding the static wheel load. Certainly the factor of time duration of the load application is one of the important details to be investigated in the development of a rational method of design.

The ultimate object in developing a theory of design is the determination of the required thickness of pavement. The supporting power of the flexible-type pavement is intimately related to its thickness, and researches designed to develop basic principles will necessarily include thickness as one of the variables of major importance.

ONLY FRAGMENTARY INFORMATION AVAILABLE ON LOAD DISTRIBUTION

The stability of the base course and the bituminous wearing course have already been mentioned. Stability in the wearing course is necessary to prevent surface failures such as shoving and rutting. Stability in the base course is necessary for the distribution of load to the subgrade. The combined stability of these two component parts of the road structure is another one of the major variables that will require intensive study. It appears that one of the important problems to be solved is the development of a suitable method for measuring this combined stability in road surfaces.

The distribution of load to the subgrade is doubtless affected by all the variables that have been mentioned as well as by the elastic characteristics of the subgrade itself. Only fragmentary information exists regarding load distribution, and very comprehensive investigations will be required to evaluate the many variables involved.

Assuming that research has solved all the problems that have been enumerated thus far, there is still the problem of determining the supporting power of the subgrade. The supporting power of a soil, or its resistance to distortion under load, is dependent on the resisting forces of internal friction and cohesion. The relative importance of each and the net result of their combined action varies widely, depending upon conditions. Subgrade research has already suggested means for increasing the load-carrying ability of soils. Needed in the development of methods of pavement design is some test which, when applied to a given subgrade, will determine the pressure intensity that can safely be imposed on the soil.

Past investigations of the bearing capacity of soils have related primarily to the foundations of buildings or other structures in which dead load is the principal burden. Therefore, the theories which have been developed from these investigations may not be applicable to pavements, where the conditions differ in two important respects. Under a structure the load is practically constant, while under a pavement the transient live load is the principal burden on the soil. Furthermore, under buildings it is permissible to anticipate foundation settlements which, if they occurred under a wheel load, would cause pavement failure. For these reasons, the requirements of a test to determine the safe bearing capacity of subgrades may be somewhat different from those of a test to determine the bearing capacity of soils in deep foundations.

It is apparent that the flexible-type bituminous road offers a fertile field for future research. The experience of the past few years justifies the expectation that further rapid progress will be made in advancing our knowledge of subgrades, bases and bituminous wearing courses. The most urgent need is for research aimed at the development of a rational method of design of the road structure as a whole.

ROADSIDE PLANTING SURVIVES DROUGHT

By **J. M. HALL**, Landscape Engineer, Iowa State Highway Commission

ROADSIDE IMPROVEMENT was first initiated on Iowa highways during the spring of 1934, financed with funds provided by the National Recovery Act. The Iowa highway commission selected as the first project a section of Primary Road No. 15 extending north from Ames 32 miles to the junction with U S 20 at Blairsburg. This road had recently been constructed and for the greater part of its length has a 100-foot right-of-way.

The general plan for grading and planting is an informal development tending to restore the natural character of the Iowa countryside. Backslopes and ditches were rounded; unsightly refuse dumps were eliminated; and several varieties of native trees, shrubs, and vines were planted. It is hoped that the final result will be an attractive roadside, blending with the adjacent topography and with existing plants.

Surveys, plans, and estimates were prepared in February and March 1934 and preliminary clearing and grubbing were started early in March prior to the completion of plans.

Planting began about May 1, immediately upon arrival of the nursery material. All stock was inspected in the nursery before contracts were awarded, and checked again upon delivery. Native Iowa peat was used as a fertilizer and mulch on the entire project.

The possibility of a dry spring and summer seemed to warrant the use of a liberal amount of peat. No accurate record was kept of the amount of peat used, but a conservative estimate is that 30 percent of the backfill was peat which was mixed with the existing soil; in addition a 2-inch layer of peat was used for mulching. The shade and flowering trees were given a close pruning to cut down moisture loss by transpiration. These two treatments, together with two complete waterings, were probably the determining factors in saving these plants through the period of drought. It is interesting to note that even after dust storms and extremely hot winds there was a sufficient supply of moisture around the plant roots 2 weeks after watering.

The preliminary survey revealed that the majority of plants would necessarily be located in areas stripped of topsoil. Because of the poor soil, late planting, and possible dry weather it was thought that plant loss might run as high as 25 percent. The spacing between plants was therefore made somewhat smaller than otherwise would have been made. The results show the plant losses to be approximately as estimated with the exception of losses of the shade trees and evergreens. These two kinds of trees survived the adverse conditions better than was expected, contrary to the usual experience in this part of the country. The use of labor unfamiliar with planting work caused some difficulty and probably resulted in some losses that otherwise could have been avoided. Table 1 shows the varieties planted and the percentage of survival at the end of the growing season last fall.

On delivery from the nursery all plants, with the exception of balled and burlapped trees, were puddled in a thick clay loam mixture and then heeled in. Each plant was watered in the temporary nursery and again puddled before being dispatched to the planting forces. A covered truck was used for transportation to the site of planting to prevent drying, as the wind was unusually hot and dry at planting time. An effort was made to order only sufficient material from the heeling in nursery each day for 1 day's planting to avoid carrying unplanted stock over-night. Watering was done with two tank trucks. Each truck was equipped with a hand-operated force pump between tank and hose, and the hose was fitted with a 2-foot length of gas pipe for a nozzle. This nozzle was pushed down to the bottom of the original excavation and water was pumped until it soaked up to the surface. This method prevented the washing of large holes around the plant and made less work in renewing the mulch on top.

TABLE 1.—*Percentage of survival of plants at end of first growing season*

	Number planted	Percentage of survival
Shade trees (1 to 2 inches in diameter at planting):		
Sugar maple (acer saccharum)	82	100
Hackberry (celtis occidentalis)	115	88
White ash (fraxinus americana)	27	96
Black walnut (juglans nigra)	36	72
American sycamore (platanus occidentalis)	66	92
Pin oak (quercus palustris)	78	80
American elm (ulmus americana)	536	91
Evergreens (4 to 5 feet in height at planting):		
Scotch pine (pinus sylvestris) [1]	15	93
White pine (pinus strobus) [1]	3	100
Small flowering trees (2 to 5 feet in height at planting):		
Red bud (cercis canadensis)	190	100
Thicket hawthorn (crataegus coccinea) [2]	89	81
Washington hawthorn (crataegus cordata) [2]	16	100
Cockspur thorn (crataegus crusgalli) [2]	80	89
Red haw (crataegus mollis) [2]	85	80
Sweet crab (malus coronaria)	30	53
Flowering crab (malus floribunda)	50	26
Prairie crab (malus ioensis)	355	48
Wild plum (prunus americana)	40	96
Purple plum (prunus pissardi)	173	74
Pussy willow (salix discolor)	172	41
Laurel leaf willow (salix pentandra)	75	16
Cathay crab (malus ioensis cathay)	15	87
Shrubs:		
Red dogwood (cornus alba sibirica)	590	14
Alternate dogwood (cornus alternifolia)	10	0
Gray dogwood (cornus paniculata)	655	26
Yellow dogwood (cornus stolonifera lutea)	175	7
Wahoo (euonymus atropurpureus)	150	93
Fragrant sumac (rhus canadensis)	730	77
Smooth sumac (rhus glabra) [3]	2,285	72
Staghorn sumac (rhus typhina) [3]	405	69
Meadow rose (rosa blanda)	215	83
Virginia rose (rosa lucida)	125	78
Jap rose (rosa multiflora)	350	44
Prairie rose (rosa setigera)	145	95
American elder (sambucus canadensis)	185	79
Coralberry (symphoricarpos vulgaris)	2,647	62
Wayfaring tree (viburnum lantana)	275	56
Nannyberry (viburnum lentago)	215	24
Vines:		
Virginia creeper (ampelopsis quinquefolia)	50	50
Bittersweet (celastrus orbiculatus)	715	78
Matrimony vine (lycium chinense)	480	99

[1] Balled and burlapped.
[2] About half received balled and burlapped.
[3] Collected stock.

In the fall all plants were pruned by an experienced workman. The plants are now in shape to start a directed growth and little maintenance will be required for another year.

Few conclusions can be drawn from the results shown to date. The plant varieties used will, in many instances, serve as experiments which will be helpful in planning future roadside work. This report deals only with experience with new planting during an abnormally dry year and is not indicative of general adaptability to roadside use. However, the care and methods used in planting seem to merit their continued use.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF MARCH 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 5,788,947	$ 3,137,314	$ 35,889	311.7	$ 2,173,060	$ 733,587	$ 840,130	133.0	$ 57,928	$ 422,187	19.3	$ 18,924	$ 831,715
Arizona	3,878,555	1,338,712	4,371,570	3,697,024	75,187	299.0	1,105,498	159,724	903,326	73.8		249,673	17.8	21,808	110,526
Arkansas	3,334,167	1,714,000	2,994,549	2,388,356	137,100	154.8	1,855,221	798,211	791,679	74.5	39,563	384,472	15.9	108,037	400,748
California	7,912,928	3,713,643	9,264,016	6,955,132		277.5	4,123,249	957,601	1,897,200	122.1		667,585	28.8	195	1,148,857
Colorado	3,437,265	2,424,504	3,950,311	3,332,568	515,300	185.1	1,913,760	67,121	1,736,717	95.3	18,307	172,487	6.7	19,269	
Connecticut	1,404,213	607,500	797,612	795,279		14.5	1,324,901	608,934	453,399	21.7		126,327	1.8		27,774
Delaware	877,566	461,697	1,052,795	868,470	177,572	42.1	287,746		274,891	6.8	8,734			362	9,234
Florida	2,469,370	1,116,600	3,076,359	2,249,668		115.8	972,872	194,891	727,825	35.7		67,730	.4	24,811	321,045
Georgia	5,045,592	2,556,745	3,669,629	3,471,969		252.9	2,603,644	1,407,053	1,161,590	129.1	58,578	385,213	31.0	107,992	1,009,942
Idaho	2,166,858	1,131,910	2,134,554	1,961,230	107,294	186.0	614,395	171,151	425,881	37.0	25,000	86,565	8.8	9,477	512,171
Illinois	4,442,467	3,060,041	1,994,217	1,957,517	19,269	38.2	3,301,037	2,421,646	879,391	51.3	36,045	952,525	18.2	27,259	1,208,855
Indiana	5,018,921	2,816,687	3,261,636	3,220,336		106.1	2,164,158	1,639,608	523,839	52.7	58,760	1,991,746	129.9	100,217	301,103
Iowa	5,027,830	2,217,361	4,814,486	4,597,019	54,420	288.6	2,138,416	390,400	1,634,873	121.9		484,574	25.5	40,411	43,495
Kansas	5,044,802	2,354,131	5,326,052	4,950,741	206,992	577.7	1,838,085	56,400	1,781,320	164.2		365,819	13.0	37,661	
Kentucky	3,751,605	1,527,324	3,621,058	3,349,367	33,571	244.3	762,859	363,396	329,247	58.1	21,000	532,536	37.2	[illegible]	631,970
Louisiana	2,710,135	1,380,419	1,831,674	1,826,216		75.1	2,072,324	[illegible]	738,415	15.5	45,353	421,033	15.3	11,459	[illegible]
Maine	1,617,560	793,644	1,358,189	1,323,504		43.8	802,573	[illegible]	563,118	13.5	17,142	204,636	6.8	17,469	[illegible]
Maryland	1,782,263	289,609	808,265	791,495	16,517	15.3	964,455	758,097	206,358	21.5	39,135			133,516	66,735
Massachusetts	1,101,716	1,632,874	1,403,571	1,010,595		37.4	546,799	52,687	442,290	9.2		538,520	10.1	38,434	652,064
Michigan	6,051,532	3,226,284	4,819,084	4,676,672		223.4	3,221,325	1,348,200	1,858,325	126.2		990,550	37.6	26,661	377,409
Minnesota	4,561,011	2,642,244	5,652,988	4,337,933	1,198,010	869.6	913,868	179,056	683,012	125.1		595,121	69.9	44,021	166,100
Mississippi	3,489,337	2,832,182	4,466,193	2,396,927	87,605	230.7	2,534,648	916,171	875,532	136.5	102,503	911,917	61.5	73,735	957,127
Missouri	5,237,532	2,132,426	4,641,195	4,103,568		187.9	2,910,307	1,065,079	1,624,109	77.1		368,429	17.7	68,886	139,888
Montana	4,463,849	2,714,208	5,463,559	4,444,343	473,230	426.3	1,835,098	4,129	1,762,011	173.3		326,627	36.4	15,377	152,340
Nebraska	3,914,481	1,982,182	5,102,140	3,868,837	54,009	366.8	2,069,944	23,149	1,656,146	92.3	11,046	229,004	15.6	11,449	43,022
Nevada	2,909,387	1,350,356	2,878,778	2,689,588	131,852	272.1	677,847	91,948	535,899	97.6	92,734	315,883	42.9	35,117	316,722
New Hampshire	692,119	484,731	638,684	612,389		10.8	524,341	79,730	422,874	12.5		18,673			43,184
New Jersey	3,173,019	951,379	1,711,231	1,691,699		31.6	1,766,328	1,472,042	105,129	18.0		466,246	3.0	9,279	380,004
New Mexico	2,846,648	1,676,769	3,033,062	2,760,948	128,175	297.5	1,258,400	85,700	1,101,806	96.6					446,788
New York	10,465,672	3,748,600	10,438,447	8,528,190	168,930	211.6	7,889,958	1,844,670	2,829,030	136.9		374,950	11.2	92,813	375,690
North Carolina	4,761,147	2,040,068	4,597,102	3,538,534	207,673	578.1	1,388,466	684,321	428,862	150.1	184,337	244,600	25.3	353,955	1,158,932
North Dakota	2,902,224	1,469,484	3,130,825	2,641,961	60,698	1,023.9	370,290	52,853	244,802	138.8	65,172	537,494	291.2	142,239	626,489
Ohio	7,277,758	3,539,256	7,439,668	7,041,589		192.4	2,913,930		2,587,065	59.3	93,600	427,500	11.4	142,569	524,690
Oklahoma	4,608,399	2,342,590	4,050,182	3,893,618	61,708	290.6	2,446,342	706,289	1,557,777	101.8	5,226	151,103	5.7	3,263	572,003
Oregon	3,052,448	1,452,741	3,233,723	3,002,596	8,928	182.8	1,766,101	10,790	1,280,914	60.2		26,403	.9	40,062	136,497
Pennsylvania	6,691,194	4,554,082	5,820,309	5,493,801	100,985	123.2	4,936,181	1,108,705	3,611,625	86.3	2,126	675,357	11.6	80,562	166,115
Rhode Island	979,367	464,572	968,005	899,627		20.5	542,465	46,205	414,131	13.6		25,194	.7	33,635	25,247
South Carolina	2,729,583	1,385,477	2,244,905	2,239,577		198.2	833,606	371,161	462,445	71.1	20,920	1,637	.1	97,925	921,395
South Dakota	3,004,739	1,523,821	2,723,908	2,219,422	46,543	458.5	795,436	588,537	185,542	186.5	125,166	875,077	137.1	72,014	416,659
Tennessee	4,240,309	2,105,453	4,618,976	3,931,870	64,152	182.7	1,416,530	236,562	1,083,506	46.3	48,798	244,625	7.7	29,278	713,111
Texas	11,588,643	6,858,253	11,732,477	11,169,217	27,364	998.1	4,396,559	363,560	3,844,088	348.1		1,329,523	98.4	[illegible]	[illegible]
Utah	2,367,205	1,066,345	2,765,227	2,277,255	365,500	237.8	797,662	84,632	502,487	61.6		8,000	.2	5,318	193,358
Vermont	928,164	466,042	970,709	909,613	28,464	47.9	277,219	10,670	249,114	13.9		166,538	5.4	7,901	21,926
Virginia	3,708,379	1,882,693	3,600,369	3,342,567	28,568	151.6	1,673,721	153,288	1,423,549	65.7	123,412	193,721	25.7	89,111	236,866
Washington	[illegible]	1,553,206	2,776,537	2,558,858	196,077	99.4	1,630,765	464,108	1,005,609	29.5	1,485	80,535	.8	33,487	[illegible]
West Virginia	[illegible]	1,140,167	1,932,305	1,851,481	60,892	71.2	554,635	111,669	426,074	20.0		286,931	9.2	[illegible]	366,271
Wisconsin	[illegible]	1,751,970	4,398,055	4,272,869	3,324	213.1	1,195,677	239,442	856,992	59.0	134,828	615,848	31.1	50,379	[illegible]
Wyoming	[illegible]	1,686,368	2,435,315	2,036,652	228,127	488.4	1,244,177	209,202	1,006,808	162.0		293,125	62.6	2,809	156,308
District of Columbia															
Hawaii	[illegible]	598,778	344,446	248,384		12.4	1,838,793	1,438,169		27.2				6,791	[illegible]
TOTALS	[illegible]	44,897,049	[illegible]	155,586,365	5,109,925	11,965.0	87,785,721	25,830,106	50,988,812	4,030.0	1,430,900	18,834,839	1,407.4	2,483,206	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF MARCH 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389 928	$ 1,064.961	$ 1,570,382	$ 1,570,269		38.5	$ 780,472	$ 671,058	$ 109,414	28.2	$ 101,345	$ 170,138	3.6	$ 47,255	$ 785,408
Arizona	807,982	305.191	627,286	613,556	$ 8,996	12.3	58,592	20,500	28,309	1.6	129,322		.2	44,604	267,886
Arkansas	1,964,534	857,025	1,553,688	1,454,881		40.6	472,541	379.392	92,849	6.9	101,076	342,738	8.7	29,185	421,439
California	4,213,986	2,219,360	3,955,814	3,410,067		46.7	2,174,878	789,009	1,072,832	17.9		607,200	6.5	14,909	539,328
Colorado	1,718,633	190,000	1,764,404	1,693,970	13,406	35.9	176,594		176,594	3.2				24,663	
Connecticut	802,407	426,500	809,564	798,075	6,949	10.3	137,740		137,740	1.2		36,796	.4	4,332	245,016
Delaware	460,409	230,849	516,399	460,282	47,610	7.2	6,570		6,570	.1				127	176,668
Florida	1,459,648	501,200	1,676,174	1,398,151	28,077	18.7	74,749		74,749	2.5		39,469	.4	61,498	358,904
Georgia	2,724,620	1,278,373	1,497,427	1,485,638		57.7	1,093,491	977,161	116,330	22.6	80,542	170,980	6.4	181,279	991,063
Idaho	1,197,829	321,126	1,162,117	1,120,140	2,643	19.4	70,593	45,372	25,221	1.7		2,156	.1	32,318	291,106
Illinois	7,476,075	2,515,835	5,922,535	5,771,026		63.1	2,214,505	1,593,239	621,266	10.3	57,163	608,346	4.5	54,647	1,286,224
Indiana	4,287,050	2,136,306	2,943,189	2,878,912		60.6	1,260,877	1,152,876	107,823	11.8	122,991	947,178	23.1	132,271	1,081,306
Iowa	2,614,472	1,311,000	1,926,082	1,839,170	7,085	53.8	976,612	774,302	140,914	11.8	1,000	474,385	10.9		688,616
Kansas	2,522,401	1,432,949	2,227,367	2,203,065	15,901	38.8	1,410,724	275,108	975,460	13.5		441,588	4.6	14,228	
Kentucky	1,927,828	954,578	1,395,790	1,371,099		31.4	709,298	492,577	211,760	6.1	63,000	192,738	5.5	1,153	550,079
Louisiana	1,708,577	744,560	680,143	679,010		17.6	1,058,149	861,500	169,968	15.2	162,272	174,807	4.6	5,795	399,785
Maine	909,878	490,045	839,187	833,094		16.4	47,071	47,071		.4		156,506	1.4	29,713	333,539
Maryland	891,132	452,515	390,127	384,134		4.1	911,650	98,129		.4	170,504		.5	238,365	452,515
Massachusetts	5,007,199	847,600	1,915,107	1,873,562		12.3	3,164,075	3,086,851	52,248	5.4		223,765	2.2	46,786	571,587
Michigan	3,500,638	1,613,142	3,240,199	3,057,771	104,400	38.8	1,520,400	412,750	1,069,750	12.6	14,950	223,700	6.8	15,166	215,292
Minnesota	3,719,143	1,421,494	3,235,674	3,003,452	196,727	108.1	387,831	172,113	207,518	10.1	7,653	146,992	6.6	535,925	870,258
Mississippi	1,744,669	354,022	685,196	644,536	27,695	25.4	884,821	729,905	109,358	23.8	283,775	95,119	11.0	86,453	121,850
Missouri	4,019,501	1,617,451	2,256,778	2,186,421		50.6	1,882,322	1,690,009	146,476	12.0	23,343	65,196	1.2	119,729	1,405,778
Montana	1,115,962	113,092	1,039,847	1,032,075		33.2	90,811	34,716	31,541	4.5	25,051	40,139	3.6	24,120	41,412
Nebraska	1,957,240	991,091	2,101,399	1,945,069	131,080	36.2	367,832	118	367,714	6.3		359,532	7.3	12,053	132,765
Nevada	500,051	100,000	479,965	456,068		9.4	49,331		49,331	.9		1,000		43,983	49,668
New Hampshire	740,335	242,366	726,187	668,776	54,054	15.9	203,382	71,559	131,613	4.8					56,699
New Jersey	3,117,921	1,809,500	2,457,304	2,327,022		21.0	1,260,270	764,347	381,132	6.0		227,303	1.0	26,552	1,201,065
New Mexico	1,674,158	529,506	1,384,181	1,384,181		31.3	373,264	193,167	180,097	8.9	9,237	69,432	2.6	87,574	279,977
New York	8,255,661	3,756,621	7,018,668	6,294,762	299,400	55.9	3,943,331	1,864,756	1,870,240	24.2		1,242,050	5.0	96,143	344,931
North Carolina	2,380,573	1,210,236	2,097,487	2,051,298	38,551	75.3	593,591	184,907	370,289	14.6	96,952	386,851	11.5	47,417	414,546
North Dakota	1,451,112	734,742	1,020,031	1,013,147		43.1	217,425	142,175	75,250	8.2	271,045	210,187	29.0	24,744	449,305
Ohio	4,335,686	2,359,503	4,528,865	4,018,173	15,000	57.8	1,757,010	226,500	1,423,860	17.2		429,390	6.0	91,013	491,254
Oklahoma	2,304,200	1,171,295	1,882,766	1,817,313	18,167	40.6	639,282	456,168	179,928	9.1		530,421	6.8	30,719	442,779
Oregon	1,526,724	867,977	1,496,763	1,459,374	10,281	28.0	442,749	66,635	357,482	7.1	518	281,669	6.1	197	218,546
Pennsylvania	4,854,988	2,397,703	3,512,419	3,277,850	88,130	55.0	1,863,552	1,480,091	294,105	16.6	33,889	1,381,192	13.8	63,158	634,275
Rhode Island	579,625	255,000	519,889	518,991		7.4	141,760		141,760	1.5				60,634	113,240
South Carolina	1,364,791	692,738	1,013,288	1,011,509		33.2	309,469	286,289	23,180	11.5	22,715	103,764	2.9	44,278	565,794
South Dakota	1,502,870	761,911	1,045,688	1,045,519	168	35.2	114,329	113,137	1,192	6.2	95,770	142,044	7.2	248,444	618,506
Tennessee	2,123,155	1,121,790	1,597,471	1,582,459		23.1	657,393	423,730	233,663	6.0	106,005	222,337	3.4	10,960	665,790
Texas	6,642,863	1,795,000	4,630,666	4,522,978		110.1	2,177,881	1,826,520	186,407	26.4	123,176	364,166	18.3	170,189	1,244,427
Utah	778,826	533,173	778,624	649,146	65,900	20.2	321,105	124,000	181,357	4.5	5,130	135,000	4.1	550	150,915
Vermont	500,509	240,611	419,125	401,575		11.9	185,602	97,248	77,285	3.9		108,192	1.7	1,686	55,134
Virginia	2,008,458	941,347	1,331,616	1,233,053	68,823	25.6	961,195	486,618	268,150	7.8	141,036	290,143	5.7	147,751	314,231
Washington	1,977,260	776,603	2,012,160	1,913,253	77,774	34.8	379,739	32,500	347,239	9.2	3,957	191,720	1.6	27,549	159,871
West Virginia	1,342,270	570,085	907,870	886,610	13,293	16.5	467,074	426,725	14,816	4.9	28,935	72,008	2.6		469,968
Wisconsin	2,596,143	1,348,513	2,496,191	2,438,534	15,575	52.3	394,078	113,026	281,052	7.5		712,101	11.6	44,583	339,785
Wyoming	1,125,332	29,416	1,008,227	1,005,262		22.3	127,280	120,070	6,629	2.6		10,287	.7		12,500
District of Columbia	968,235	243,460	922,671	696,281	226,390	6.5	250,164	250,164		.2				21,790	17,070
Hawaii															
TOTALS	115,793,487	48,879,361	91,219,997	86,380,559	1,582,075	1,710.1	39,763,454	24,054,088	13,128,461	439.9	2,282,352	12,630,725	261.7	3,076,488	21,538,100

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF MARCH 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 1,035,011	$ 1,034,114		77.2	$ 1,389,829	$ 953,441	$ 436,388	96.1		$ 303,770	21.7	$ 44,898	$ 324,803
Arizona	525,423	998,032	592,872	516,393	$ 62,422	51.3	330,329	9,030	279,107	27.6		318,360	27.5		338,143
Arkansas	1,449,634	857,024	1,111,962	1,108,519		140.1	472,332	267,263	204,227	56.8	$ 5,473	179,612	17.4	68,378	473,185
California	3,480,440	1,999,203	3,583,430	2,984,134		164.3	1,284,274	494,605	667,456	37.1		442,178	21.3	1,701	889,569
Colorado	1,718,632	871,502	1,877,058	1,608,632	75,447	189.0	947,720	110,000	505,358	145.2		244,625	8.1		46,072
Connecticut	659,120	420,868	160,282	160,282		3.1	740,403	498,838	235,769	16.4					185,099
Delaware	481,113	230,849	295,307	218,550	72,707	26.7	381,126	262,563	118,329	33.0					39,813
Florida	1,302,816	1,043,543	1,284,205	1,275,634		74.8	458,016		458,016	25.7		493,061	22.4	27,182	92,466
Georgia	2,320,973	1,278,373	1,303,408	1,300,400		97.0	942,004	810,729	131,275	60.1	33,125	113,485	17.6	176,719	1,033,613
Idaho	1,121,562	824,450	1,330,051	1,104,855	56,671	156.1	477,984		459,147	52.5		70,156	7.8	16,707	238,476
Illinois	5,652,228	3,345,525	2,054,913	2,034,422		133.5	5,637,384	3,603,673	2,033,711	298.4	9,848	1,311,814	53.1	4,285	
Indiana	731,872	135,970	395,321	394,018		44.2	310,433	310,433		43.4		121,680	11.5	27,421	14,290
Iowa	2,413,358	1,590,000	2,101,503	1,931,498	109,800	318.2	1,348,910	396,650	787,975	205.1	28,200	679,300	158.9	57,010	12,925
Kansas	2,522,401	1,330,595	2,190,456	2,113,655	67,209	214.0	1,201,110	381,253	819,857	80.9	27,493	443,529	19.6		
Kentucky	1,837,926	1,330,409	1,825,311	1,715,993	16,263	210.0	988,618	107,202	865,149	112.1		454,997	70.8	14,731	
Louisiana	1,409,879	838,953	959,544	957,635		45.3	413,030	319,555	93,475	17.6	128,782	481,555	27.4	3,907	263,923
Maine	842,479	421,897	1,072,024	840,001	147,039	87.4	277,470		256,412	20.9		16,526	.7	2,478	7,920
Maryland	891,132	1,001,934	733,524	692,648		52.1	418,906	172,531	246,375	24.1	25,953	355,208	9.5		400,351
Massachusetts	488,185	870,000	469,741	469,741		15.2						115,370	5.5	18,444	754,630
Michigan	3,184,057	1,613,142	2,877,165	2,825,960	16,400	205.6	1,041,027	341,727	684,400	41.5		399,525	52.7	16,370	12,817
Minnesota	2,376,415	1,361,813	2,318,291	2,203,650	68,916	256.9	1,197,593	155,444	910,050	115.0		116,545	21.1	17,321	266,303
Mississippi	1,744,669	354,023	854,774	854,774		99.5	750,282	750,282		58.2	87,197	101,740	27.1	52,416	252,283
Missouri	2,923,273	2,423,863	2,896,461	2,687,673	133,569	602.8	1,059,762	195,938	818,570	182.3	39,613	914,384	183.8	48	557,340
Montana	1,859,937	942,434	1,829,552	1,782,524	44,554	229.9	490,934		490,934	44.0		327,939	34.6	77,413	79,007
Nebraska	1,957,240	991,091	2,109,659	1,956,988	147,789	402.5	672,110		672,110	74.5		91,040	11.9	252	80,152
Nevada	1,136,479	852,000	1,295,902	1,093,255	151,347	148.6	218,290		218,290	20.4		170,922	28.3	43,224	311,442
New Hampshire	477,385	242,365	571,499	447,963	77,387	28.4	114,607	29,000	82,590	5.9		57,479	3.4	423	24,909
New Jersey	55,099	460,000	56,528	55,099		.5						111,963	1.7		348,037
New Mexico	1,272,129	735,425	1,269,889	1,235,198	34,691	212.9	454,629	36,931	417,698	67.9		184,277	18.4		98,759
New York	3,608,768	3,822,700	3,316,753	2,953,509	28,089	83.8	3,989,410	625,700	2,564,490	186.6		1,039,550	106.1	29,559	190,571
North Carolina	2,380,573	1,590,637	2,138,433	2,137,656		224.2	1,331,929	215,387	1,086,994	143.4		296,409	42.0	27,530	[illegible]
North Dakota	1,451,112	734,741	913,405	913,168		280.1	330,472	310,175	20,297	85.3	165,596	240,529	130.3	62,173	473,316
Ohio	3,871,148	1,966,253	3,977,797	3,711,559	10,200	298.6	757,760	73,810	678,850	92.3		703,270	13.5	25,778	573,933
Oklahoma	2,304,199	1,171,295	1,823,427	1,718,816		224.8	1,442,619	582,509	695,789	87.2		182,048	8.8	2,874	[illegible]
Oregon	1,526,724	777,096	1,697,774	1,507,131	29,332	113.2	687,640	19,526	627,732	51.0		119,430	10.4	67	[illegible]
Pennsylvania	7,344,822	2,639,003	6,431,620	6,199,801	88,067	544.0	3,222,796	1,145,021	2,014,101	206.4		399,232	14.6		[illegible]
Rhode Island	439,716	295,000	409,735	399,703		33.2	212,563		212,563	6.7				40,014	82,438
South Carolina	1,364,791	692,739	1,060,256	1,060,256		113.1	941,408	255,654	646,718	120.6		46,021	[illegible]	48,881	
South Dakota	1,502,870	761,911	1,195,457	1,147,283	48,151	338.0	370,517	320,417	50,100	102.7	35,170	93,820	53.6		[illegible]
Tennessee	2,123,155	1,075,748	1,369,700	1,313,934		111.8	1,145,785	729,642	416,143	57.0	4,504	139,129	3.9	[illegible]	[illegible]
Texas	6,012,518	3,638,000	6,170,005	5,694,644		756.6	1,780,272	270,911	1,509,361	141.6		1,213,663	89.5	[illegible]	[illegible]
Utah	1,048,677	533,173	1,194,178	955,732	114,800	185.6	387,521	92,945	218,373	65.5		152,355	20.6		[illegible]
Vermont	438,880	241,354	474,394	436,802	16,569	37.2	118,931		113,646	8.4		111,102	6.0	[illegible]	[illegible]
Virginia	1,699,920	941,347	1,598,958	1,536,980	8,753	210.8	534,709	123,775	399,751	35.2	8,850	[illegible]	33.3	[illegible]	[illegible]
Washington	[illegible]	776,603	1,075,591	1,044,520	7,095	63.7	389,538	36,153	342,156	40.7		344,573	12.0		[illegible]
West Virginia	1,118,559	570,083	733,482	701,270		42.0	547,924	386,859	161,065	20.6	25,237	59,141	1.7	[illegible]	[illegible]
Wisconsin	2,431,220	1,341,354	2,311,887	2,144,491	48,583	170.4	580,381	202,460	321,763	15.1	66,000	826,770	42.6	[illegible]	[illegible]
Wyoming	1,125,332	571,928	1,152,941	1,057,939	74,683	157.2	99,718	27,126	72,591	12.9		207,168	29.9	[illegible]	[illegible]
District of Columbia	950,234	730,382	1,080,288	950,234	130,054	10.8	315,899		315,899	3.8		65,390	.4		[illegible]
Hawaii	177,718	351,000	178,209	177,718		4.9									[illegible]
TOTALS	92,869,917	56,230,590	80,759,933	75,367,354	1,886,587	8,291.1	43,206,904	15,625,158	25,361,050	3,445.7	693,041	[illegible]	[illegible]	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF MARCH 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 8,394,340	$ 5,741,697	$ 35,889	427.4	$ 4,343,362	$ 2,358,085	$ 1,385,932	257.4	$ 159,273	$ 896,094	44.7	$ 111,077	$ 1,941,926
Arizona	5,211,360	2,641,935	5,591,728	4,826,973	146,605	362.6	1,494,419	189,254	1,210,742	103.0	129,322	568,033	45.5	66,412	716,555
Arkansas	6,748,335	3,428,049	5,660,198	4,951,756	137,101	335.5	2,800,094	1,444,866	1,088,755	138.2	146,112	906,822	42.0	205,600	1,295,372
California	15,607,354	7,932,206	16,873,261	13,349,334		488.6	7,582,401	2,241,216	3,637,488	177.0		1,716,964	56.5	16,305	2,577,754
Colorado	6,874,530	3,486,006	7,591,774	6,635,170	604,153	410.0	3,038,075	177,121	2,418,670	243.8	18,307	417,112	14.8	43,932	46,072
Connecticut	2,865,740	1,454,868	1,767,458	1,753,636	6,949	27.8	2,203,044	1,107,773	826,908	39.2		163,122	2.2	4,332	457,889
Delaware	1,819,088	923,395	1,864,501	1,547,303	297,889	76.0	675,442	262,563	399,791	39.9	8,734			489	225,715
Florida	5,231,334	2,661,343	6,036,737	4,923,452	28,078	209.4	1,505,637	194,831	1,260,590	63.9		600,260	23.1	113,491	772,415
Georgia	10,091,185	5,113,491	6,470,464	6,258,007		407.6	4,639,138	3,194,943	1,409,195	211.8	172,245	669,678	55.0	465,990	3,034,618
Idaho	4,486,249	2,277,486	4,626,722	4,186,225	166,607	361.5	1,162,972	216,522	910,249	91.2	25,000	158,877	16.8	58,502	1,041,753
Illinois	17,570,770	8,921,401	9,971,665	9,762,965	19,269	234.8	11,152,926	7,618,558	3,534,368	360.1	103,056	2,672,685	75.9	86,191	2,495,079
Indiana	10,037,843	5,088,963	6,600,146	6,493,266		210.9	3,735,468	3,102,917	631,661	107.8	181,751	3,060,603	164.5	259,909	1,396,699
Iowa	10,055,660	5,118,361	8,842,071	8,367,687	171,705	660.5	4,463,938	1,561,352	2,563,702	338.8	29,200	1,638,259	195.3	97,421	745,036
Kansas	[illegible]	5,117,675	9,743,674	9,267,460	290,102	830.6	4,449,920	712,761	3,576,637	258.6	27,493	1,250,936	37.2	31,889	
Kentucky	7,517,359	3,818,311	6,842,159	6,436,458	49,834	435.8	2,460,774	903,175	1,406,156	176.3	144,000	1,180,272	113.5	33,726	1,182,049
Louisiana	5,828,591	2,963,932	3,471,312	3,462,861		138.0	3,543,503	2,001,162	1,001,858	48.3	336,407	1,077,936	47.4	28,161	884,078
Maine	3,309,917	1,711,586	3,269,400	2,996,599	147,039	147.6	1,127,115	286,526	819,530	34.7	17,142	377,668	8.9	9,650	367,349
Maryland	3,564,527	1,810,058	1,931,916	1,868,277	16,517	71.5	2,295,011	1,028,757	452,733	46.0	235,592	355,208	10.0	431,901	985,601
Massachusetts	6,597,100	3,350,474	3,788,419	3,353,899		65.0	3,710,874	3,139,538	494,538	14.6		877,654	17.8	103,664	1,978,281
Michigan	12,736,227	6,452,568	10,936,447	10,560,404	120,800	467.8	5,782,752	2,102,677	3,612,475	180.3	14,950	2,113,775	97.0	58,197	605,518
Minnesota	10,656,569	5,425,551	11,206,953	9,545,036	1,463,653	1,234.6	2,499,292	506,613	1,800,579	250.2	7,653	858,658	97.6	597,267	1,302,661
Mississippi	6,978,675	3,540,227	6,006,163	3,896,237	115,300	355.6	4,169,751	2,396,358	984,390	218.5	473,475	1,108,776	99.5	212,604	1,331,260
Missouri	12,180,306	6,173,740	9,794,434	8,977,662	133,569	841.2	5,852,391	2,951,026	2,589,155	271.4	62,955	1,348,010	202.7	188,663	2,103,006
Montana	7,439,748	3,769,734	8,332,958	7,258,942	517,724	689.4	2,416,842	38,646	2,284,486	221.8	25,051	694,725	74.6	116,910	272,759
Nebraska	7,828,961	3,964,364	9,313,198	7,770,894	332,878	805.5	3,109,886	23,267	2,695,971	173.1	11,046	679,576	34.7	23,754	255,939
Nevada	4,545,917	2,302,356	4,654,645	4,233,911	283,199	430.1	945,468	91,948	853,520	118.9	92,734	487,805	71.2	122,324	677,832
New Hampshire	1,909,839	969,462	1,936,370	1,729,128	131,441	55.2	842,330	180,288	637,077	23.2		76,152	3.4	423	124,792
New Jersey	6,346,039	3,220,879	4,225,064	4,073,819		53.0	3,026,598	2,236,389	486,260	24.0		805,513	5.7	35,831	1,929,106
New Mexico	5,792,935	2,941,700	5,687,122	5,380,327	162,865	541.8	2,086,293	315,798	1,699,602	173.3	9,237	253,709	21.0	87,574	825,524
New York	22,330,101	11,327,921	20,773,868	17,770,460	496,419	351.3	15,822,699	4,335,126	7,263,760	347.7		2,656,550	122.3	218,515	911,192
North Carolina	9,522,293	4,840,941	8,833,022	7,727,488	246,224	877.6	3,313,985	1,084,614	1,886,145	308.2	281,289	927,860	78.7	428,902	1,780,712
North Dakota	5,834,448	2,938,967	5,064,260	4,568,276	60,698	1,347.1	918,186	505,203	340,348	232.3	501,814	988,310	450.5	229,156	1,549,610
Ohio	15,484,592	7,865,012	15,946,330	14,771,322	25,200	548.9	5,428,700	300,310	4,689,775	168.8	93,600	1,560,160	30.9	319,360	1,589,877
Oklahoma	9,216,798	4,685,180	7,756,375	7,429,747	79,875	556.0	4,528,242	1,744,966	2,433,494	198.1	5,228	863,572	21.3	36,856	1,308,239
Oregon	6,106,896	3,097,814	6,488,260	5,969,102	48,540	323.9	2,496,490	96,950	2,266,127	118.3	518	427,503	17.4	40,326	355,644
Pennsylvania	18,891,004	9,590,788	15,764,348	14,971,452	277,133	722.1	10,022,529	3,733,817	5,919,831	309.3	36,015	2,455,781	40.0	149,720	937,993
Rhode Island	1,998,708	1,014,572	1,897,629	1,818,321		61.1	896,788	46,205	768,453	21.8		25,194	.7	134,183	220,925
South Carolina	5,459,165	2,770,954	4,373,449	4,311,341		344.4	2,084,483	913,104	1,132,343	203.3	43,635	151,422	10.6	191,084	1,487,189
South Dakota	6,011,479	3,047,643	4,971,053	4,412,224	94,862	831.8	1,280,332	1,022,090	236,835	295.4	256,106	1,110,941	203.9	321,058	1,605,004
Tennessee	8,492,619	4,302,991	7,586,097	6,828,263	64,152	317.6	3,219,708	1,389,935	1,733,372	109.3	159,308	606,090	15.0	115,113	1,899,377
Texas	24,244,024	12,291,253	22,533,149	21,406,839	27,364	1,864.8	8,354,712	2,460,991	5,539,857	516.1	123,176	2,912,352	206.2	253,018	3,811,680
Utah	4,194,708	2,132,691	4,741,028	3,882,132	546,200	443.6	1,506,289	301,578	902,217	131.6	5,130	295,355	24.9	5,868	388,918
Vermont	1,867,573	948,007	1,864,228	1,747,990	45,033	97.0	581,752	107,918	440,045	26.2		385,832	15.1	11,665	77,097
Virginia	7,416,757	3,765,387	6,530,943	6,112,600	106,144	388.0	3,169,625	763,682	2,091,450	108.7	273,297	749,153	69.7	267,177	818,641
Washington	6,115,867	3,106,412	5,864,289	5,516,631	280,945	197.8	2,400,043	532,762	1,695,004	79.4	5,442	616,927	14.4	61,031	513,536
West Virginia	4,474,234	2,280,335	3,571,657	3,439,361	74,185	129.6	1,569,633	925,253	601,955	45.6	54,172	418,081	13.6	55,448	1,186,115
Wisconsin	9,724,881	4,941,837	9,206,163	8,855,894	67,483	435.8	2,170,135	554,927	1,459,807	81.6	202,828	2,154,718	85.3	111,231	1,259,829
Wyoming	4,501,327	2,287,712	4,596,483	4,101,853	302,810	667.9	1,471,176	356,398	1,088,028	177.5		510,540	93.3	43,076	386,334
District of Columbia	1,918,469	973,842	2,002,959	1,646,515	356,444	17.3	566,063	250,164	315,899	3.9		65,390	.4	21,790	236,109
Hawaii	1,871,062	949,778	522,655	426,102		17.3	1,838,793	1,438,169		27.2				6,791	949,778
TOTALS	394,000,000	200,000,000	352,249,744	317,334,298	8,578,587	21,966.2	170,756,079	65,509,352	89,478,323	7,915.6	4,412,293	47,096,653	3,192.7	6,744,057	54,846,437

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 3 MAY 1935

ROADSIDE STATION FOR DETERMINING WEIGHTS AND DIMENSIONS OF TRUCKS

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 16, No. 3 May 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

A STUDY OF THE WEIGHTS AND DIMENSIONS OF TRUCKS

ported by J. T. THOMPSON, Highway Research Specialist, U. S. Bureau of Public Roads, and Professor of Civil Engineering, the Johns Hopkins University

DETERMINING THE WEIGHTS AND DIMENSIONS OF TRUCKS.

ow do the over-all dimensions of loaded motor vehicles vary with manufacturer's rated capacity?

ow are the gross loads of motor vehicles distributed to the various axles?

o what extent do operators exceed the manufacturer's recommended loading, and how does prevalency of this "overloading" vary with manufacturer's ratings?

o what extent are tires being similarly overloaded?

THESE ARE typical of the questions which should be answered by those who must consider dimensions and load concentrations in providing clear- ice and strength in the design of highways and high- ay bridges, by highway economists who would properly locate highway costs to the various classes of vehicles, manufacturers of both vehicles and tires, and by ghway administrators and legislators who would in- lligently restrict motor vehicle size and weight and gislate fair tax rates to sustain highway programs.

Those who have had to seek the answers to these and milar questions know that hitherto existing data, such manufacturer's specifications, fail to provide them. far as the writer knows, there is no way to obtain is information except by establishing roadside clinics" where vehicles may be studied as they pass.

OBSERVATIONS MADE ON TWO MAIN TRUCK ROUTES

The following data have been obtained from just such inics. During the summer and fall of 1934 the Bu- au of Public Roads of the United States Department of Agriculture with the cooperation of the Johns Hopkins University, the Maryland State Roads Commission, and the Commissioner of Motor Vehicles of Maryland, operated two stations at which commercial vehicles were weighed and measured. One of these was located on Route U S 40, leading north from Baltimore toward Philadelphia, the other on Route U S 1 leading south from Baltimore toward Washington. These stations were operated alternately for periods of approximately 2 weeks from the middle of June to the middle of November. During the entire period 10,700 vehicles were observed, 7,100 when loaded and 3,600 when empty. It is believed that the data constitute a representative sample of truck traffic on main highways in this area. Further investigation is needed to determine if the data are representative of truck traffic on main highways generally.

The field party of 4 men consisted of a uniformed officer to direct traffic, a notekeeper, and 2 others who shared the duties of weighing and measuring. Aside from the scales no other special equipment was used. A cloth tape and a level-rod with a horizontal arm for calipering heights answered every purpose.

In order to avoid the recurrence of data relating to identical vehicles frequently passing the station, identification cards were issued to all operators and no vehicle was recorded more than once loaded and once empty when proceeding in each direction during any one 2-week period.

The procedure was as follows: All commercial vehicles were stopped. Identification cards, if presented, were examined. If a card were presented indicating that the vehicle, loaded or empty, had already been recorded when traveling in the same condition and in the same direction during the current 2-week period, the vehicle was permitted to pass. Otherwise it was run on the scales and weighed first with all wheels on the platform. It was then moved ahead by stages until, first the forward axle, and then each successive axle was off the platform, determining after each movement the weight carried on the axles remaining on the platform. At the same time the over-all length, height, width, and wheel base were determined; the manufacturer's marker and registration data were inspected for make of vehicle and manufacturer's rated capacity; and the license number was noted.

As the field reports came into the office the information contained in and derived from them was tabulated on large ruled master sheets, and these were used in segregating and analyzing the data. Where the data permitted, pay loads were determined by subtracting the measured empty weights of vehicles from their gross weights as measured on loaded trips. The determination was facilitated by preparing, for each vehicle initially observed, a file card, bearing the license number, on which was entered after each observation of the same vehicle a reference to the pertinent field data sheet.

Before proceeding to the remainder of this report, the reader should have in mind the size and weight restrictions of Maryland laws because of their influence upon the data. From the beginning of the study in June until the middle of October no attention was paid to violations of these laws nor were penalties of any kind imposed. This was done intentionally to encourage unrestricted operation. The number of observed weight violations was small—less than one percent. After the middle of October, at the insistence of State authorities, the laws were enforced and nine arrests were made for overweight, 1,500 weighings being recorded during the corresponding period.

The Maryland laws may be briefly summarized as follows:

Maximum dimensions

Width	96 inches.
Length	Unrestricted
Height	Unrestricted.

Maximum gross weights

On solid tires	650 pounds per inch of tire width.
On pneumatic tires:	
Single unit, 4 wheels, 2 axles	25,000 pounds.
Single unit, 6 wheels, 3 axles	40,000 pounds.
Combination of 2 vehicles (tractor and semitrailer or tractor and full trailer) combined weight	40,000 pounds.[1]

GROSS WEIGHTS NOT IN PROPORTION TO RATED CAPACITIES

Reference will be made in this report to the term "manufacturer's rated capacity" as applied to both vehicles and tires. Applied to single vehicles and tires, the term as used means the carried load which the manufacturer recommends as safe and economical for the vehicle or tire in question. Applied to tractor-semitrailer combinations, it refers to the carried load of the semitrailer only.

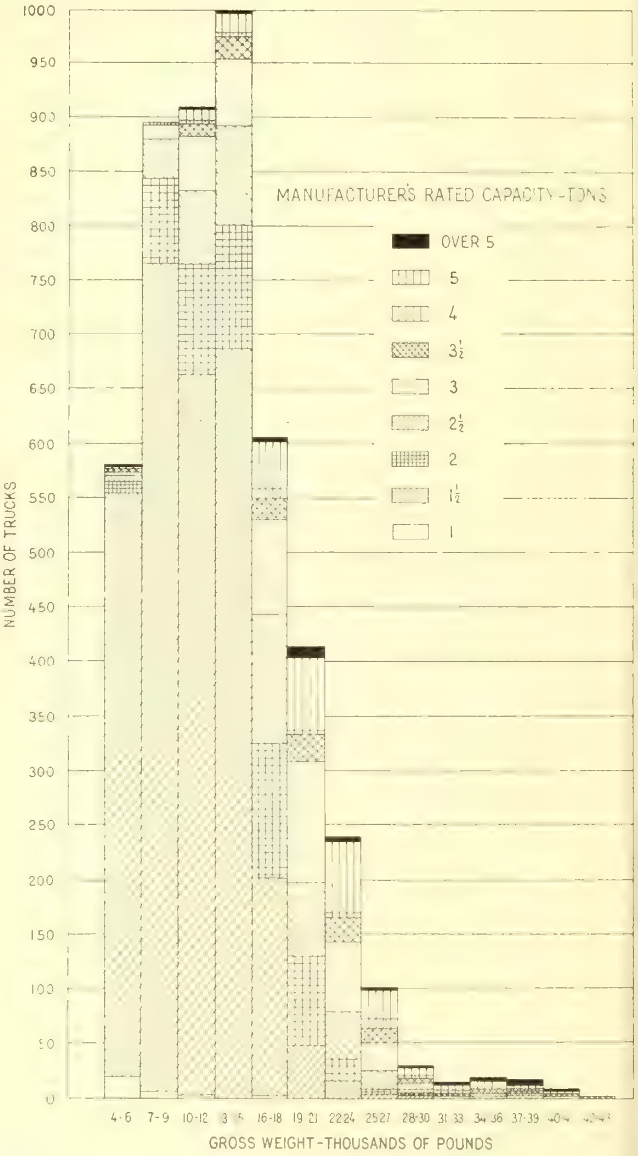

FIGURE 1.—FREQUENCY DISTRIBUTION BY GROSS WEIGHTS LOADED SINGLE VEHICLES.

Figure 1 and table 1 show the frequency distributio by the gross weights of loaded single vehicles, expresse in terms of numbers of vehicles and the percentages the total number of loaded vehicles of each capacit class having gross weights falling within various cla limits, defined to the nearest thousand pounds. I tables 2 and 3 these data are segregated respective into 4-wheel and 6-wheel classes. As stated abov 4-wheel single vehicles may legally carry 25,000 poun and 6-wheelers 40,000 pounds.

It is immediately evident that the gross loads vehicles of small capacity are much greater in propo tion to the rated capacity than are those of large capa ity trucks. Comparing the 1½- and 5-ton classes table 1, for example, the ratio of rated capacities 3.33. If gross weight were proportional to capacit 5-ton trucks would have an average gross weight 3.33 by 10,500 equals 35,000 pounds; actually th average 21,600 pounds.

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[1] There is nothing in the Maryland law to prevent adding to these combinations of 2 vehicles an indefinite number of units weighing as much as 40,000 pounds each.

TABLE 1.—*Frequency distribution of gross weights of all loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average gross weight	Gross weight, 1,000 pounds: 4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45	Total
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	[illegible]
ton	6,400	70.0	20.0	6.7		3.3										[illegible]
tons	10,500	18.4	26.1	22.6	23.7	6.9	1.7	0.4	0.1	0.1						[illegible]
tons	14,400	1.9	14.5	19.3	21.1	23.1	15.4	3.8	.7	.2						[illegible]
tons	16,300	1.3	7.9	14.6	20.1	26.0	14.6	9.6	4.2	[illegible]		[illegible]	0.4			[illegible]
tons	18,100	.2	3.3	11.7	15.0	20.4	26.2	14.8	[illegible]	1.2	[illegible]			0.2		[illegible]
tons	20,600	2.3		7.6	15.3	[illegible]	19.0	17.6	11.4	3.1	1.5	[illegible]	.8	.8	[illegible]	[illegible]
tons	21,600		2.9	8.6	8.6	22.8	5.6	8.6	22.8	8.6	8.6		2.9			[illegible]
tons	21,600	.4		4.2	6.9	[illegible]	25.6	25.6	[illegible]	[illegible]	1.5	[illegible]	[illegible]	1.1		[illegible]
ver 5 tons	25,400	2.3		4.7	4.7	11.6	23.2	9.3	9.3	2.3	[illegible]	4.7	13.9	[illegible]		[illegible]

TABLE 2.—*Frequency distribution of gross weights of loaded 4-wheel single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average gross weight	Gross weight, 1,000 pounds: 4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45	Total
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	Number
ton	6,400	70.0	20.0	6.7		3.3										[illegible]
tons	10,100	19.8	26.9	23.5	23.5	5.6	0.4	0.1	0.1							[illegible]
tons	14,300	2.0	14.2	20.1	21.7	22.9	14.8	3.6	.7							[illegible]
tons	16,000	1.4	8.4	15.2	20.7	25.4	14.9	9.8	4.0	.2						129
tons	17,800	.3	3.3	11.4	15.7	20.4	27.6	15.4	5.3	[illegible]	0.3					[illegible]
tons	18,600	2.8		9.4	17.0	17.9	20.8	18.9	12.3	.9						[illegible]
tons	18,800			17.6	5.9	35.3	5.9	11.8	23.6							[illegible]
tons	20,100	.5		5.1	7.9	18.1	28.1	28.2	10.7	.9	.5					216
ver 5 tons	19,200	4.3		8.7	8.7	17.4	34.9	4.3	17.4		4.3					23

TABLE 3.—*Frequency distribution of gross weights of loaded 6-wheel single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average gross weight	Gross weight, 1,000 pounds: 4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36	37-39	40-42	43-45	Total
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	Number
ton																
tons	14,900	2.2	[illegible]	12.9	25.7	[illegible]	17.8	[illegible]	[illegible]							[illegible]
tons	17,300		13.7	4.5	9.1	27.3	31.8	9.1		4.5						22
tons	21,200			6.9	13.8	31.0	10.3	6.9	6.9	13.8		3.4	6.9			29
tons	22,100		3.1	12.5	6.3	18.8	9.4	6.3	9.4	[illegible]	6.3	3.1	6.3	3.1		32
tons	29,100				8.0		12.0	12.0	8.0	12.0	8.0	28.0	4.0	[illegible]	[illegible]	[illegible]
tons	24,300		5.6		11.1	11.1	5.6	5.6	22.2	16.7	16.7		[illegible]			[illegible]
tons	28,500				2.2	[illegible]	13.0	13.0	4.3	13.0	6.6	[illegible]	13.0	[illegible]		[illegible]
ver 5 tons	32,500					5.0	10.0	15.0		5.0	5.0	10.0	30.0	20.0		20

In tables 4, 5, and 6 vehicles of the heavier gross-weights are analyzed according to rated capacity. Table 4 is a classification of all single vehicles of gross weights exceeding 21,000 pounds. Table 5 is a similar classification of the 4-wheel vehicles only, and table 6 deals similarly with 6-wheel vehicles only.

Table 4 shows that of 4,839 single vehicles observed 427 or 8.9 percent had gross weights in excess of 21,000 pounds. It is a common belief that such gross weights are associated mainly with vehicles of 5- and over-5-ton rated capacity. Actually, as shown by table 4, only 144 or a trifle over one-third of the 427 vehicles of gross weight exceeding 21,000 pounds were of these two largest rated-capacity classes. Over a fourth of the total number—112 out of 427—were vehicles of 2½ tons rated capacity or smaller, and 16 were trucks of 1½ tons rated capacity, sizes generally well within the common conception of medium vehicles.

Referring again to table 4, it will be seen that only 190 (4.0 percent) of all loaded vehicles were found to have gross weights in excess of 24,000 pounds, and that the number of these that were of the 5- and over-5-ton capacity classes was only 73 (38.4 percent). Again vehicles rated at 2½ tons capacity and less were found to constitute a very considerable percentage (18.4 percent) of the total, and still a few 1½-ton trucks were included.

As shown by table 1, it is not until gross weight rises in excess of 30,000 pounds that the last of the 1½- and 2-ton trucks disappear; but the 61 trucks, shown by table 4 to be in excess of that weight, include representatives of all rated-capacity classes from 2½-ton upward. In fact, not far from half of the number were rated at less than 5 tons capacity.

The final columns of table 4 show that 10 or about 0.2 percent of all observed loaded single vehicles weighed above 40,000 pounds. All of these were rated at 3-ton capacity or more and 7 of the 10 were of the 5- and over-5-ton classes. By comparison with table 6 it will be seen that all of these trucks were 6-wheel vehicles, and all were violators of the Maryland law which sets the limit for such trucks at 40,000 pounds;

Table 4.—*Classification of all heavy-loaded single vehicles according to manufacturer's rated capacity and gross weight*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having gross weights exceeding—							
		21,000 pounds		24,000 pounds		30,000 pounds		40,000 pounds	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1 ton	30								
1½ tons	2,920	16	3.8	3	1.6				
2 tons	533	25	5.9	5	2.6				
2½ tons	458	71	16.6	27	14.2	3	4.9		
3 tons	427	99	23.2	36	19.0	7	11.5	1	10.0
3½ tons	131	54	12.6	31	16.3	12	19.7	2	20.0
4 tons	35	18	4.2	15	7.9	4	6.6		
5 tons	262	121	28.3	54	28.4	21	34.4	3	30.0
Over 5 tons	43	23	5.4	19	10.0	14	22.9	4	40.0
Total	4,839	427	100.0	190	100.0	61	100.0	10	100.0
Percentage of total loaded vehicles	100	8.9		4.0		1.2		0.2	

Table 5.—*Classification of heavy-loaded 4-wheel single vehicles according to manufacturer's rated capacity and gross weight*

Manufacturer's rated capacity	Total all loaded 4-wheel vehicles	Loaded 4-wheel vehicles having gross weights exceeding—					
		21,000 pounds		24,000 pounds		30,000 pounds	
	Number	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1 ton	30						
1½ tons	2,695	4	1.3	5	2.1		
2 tons	511	22	7.3	4	4.2		
2½ tons	429	60	19.8	18	18.7		
3 tons	395	84	27.7	23	23.9	1	33.3
3½ tons	106	34	11.2	14	14.6		
4 tons	17	6	2.0	4	4.2		
5 tons	216	87	28.8	26	27.1	1	33.3
Over 5 tons	23	6	2.0	5	5.2	1	33.4
Total	4,422	303	100.0	96	100.0	3	100.0
Percentage of total loaded 4-wheel vehicles	100	6.9		2.2		0.1	

Table 6.—*Classification of heavy-loaded 6-wheel single vehicles according to manufacturer's rated capacity and gross weight*

Manufacturer's rated capacity	Total all loaded 6-wheel vehicles	Loaded 6-wheel vehicles having gross weights exceeding—							
		21,000 pounds		24,000 pounds		30,000 pounds		40,000 pounds	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1 ton									
1½ tons	225	12	9.7	1	1.0				
2 tons	22	3	2.4	1	1.1				
2½ tons	29	11	8.9	9	9.6	3	5.2		
3 tons	32	15	12.1	13	13.8	6	10.3	1	10.0
3½ tons	25	20	16.1	17	18.1	12	20.7	2	20.0
4 tons	18	12	9.7	11	11.7	4	6.9		
5 tons	46	34	27.4	28	29.8	20	34.5	3	30.0
Over 5 tons	20	17	13.7	14	14.9	13	22.4	4	40.0
Total	417	124	100.0	94	100.0	58	100.0	10	100.0
Percentage of total loaded 6-wheel vehicles	100	29.8		22.6		13.9		2.4	

yet in view of the fact that their heavier loads were carried on six wheels, many of these vehicles unquestionably made less demand upon the strength of the road than the heavier 4-wheel vehicles of gross weights between 21,000 and 24,000 pounds.

By comparing tables 4, 5, and 6, it will be seen that 58 of the 61 vehicles observed to have gross loads over 30,000 pounds were 6-wheelers. The three 4-wheel vehicles all weighed less than 40,000 pounds, and, as shown by table 5, represented the 3-, 5-, and over-5-ton rated-capacity classes.

In the larger groups of vehicles of gross weights exceeding 24,000 and 21,000 pounds the numbers of 4-wheel vehicles are relatively higher, made so by the preponderance of the lighter gross loads carried on 4 wheels.

VEHICLES OF ALL RATED CAPACITIES FOUND TO CARRY HEAVY LOADS

Table 7 and figure 2 show the gross-weight-frequency distribution for tractor-semitrailer combinations. The tendency to heavier loading of the smaller units in relation to capacity is again evident. If gross weights were proportional to semitrailer capacities, the 5-ton class would average 3.33 by 20,800 equals 69,200 pounds, whereas it actually averages 27,100 pounds.

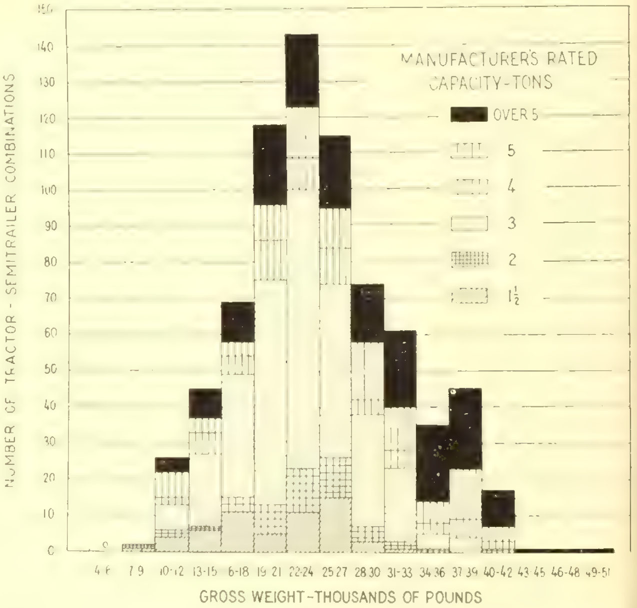

Figure 2.—Frequency Distribution by Gross Weights of Loaded Tractor-Semitrailer Combinations.

Three cases of overloading, producing gross weights of over 42,000 pounds, are chargeable to the over-5-ton class. The group of gross weights between 40,000 and 42,000 pounds, which with the tolerance permitted by the State roads commission includes only legally loaded vehicles, shows a rated-capacity range of from 2 to over 5 tons.

In table 8 the heavier tractor-semitrailer combinations are shown in groups exceeding each of several gross-weight limits corresponding to those shown for single vehicles in tables 4, 5, and 6. These data show that the numbers of combinations exceeding the limits shown constitute a much larger percentage of the total number of such vehicles than in the case of either 4- or 6-wheel single vehicles. Nearly two-thirds of all semitrailer combinations observed exceed 21,000 pounds gross weight, and almost half weigh more than 24,000 pounds gross. While about one-fifth of the total number exceed 30,000 pounds, only 2.7 percent weigh more than 40,000 pounds. Here again it is apparent that the heavier gross loads are not by any means carried exclusively on vehicles of the larger rated-capacity classes. On the contrary the smaller rated-

Table 7.—*Frequency distribution of gross weights of loaded tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average gross weight	Gross weight, 1,000 pounds															
		7–9	10–12	13–15	16–18	19–21	22–24	25–27	28–30	31–33	34–36	37–39	40–42	43–45	46–48	[illegible]	[illegible]
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	[illegible]
½ tons	20,800	1.8	7.0	10.5	19.3	8.7	19.3	26.3	5.3	1.8							[illegible]
tons	23,200	2.1	4.3	2.1	8.5	17.0	25.6	23.4	8.5	4.3	2.1		2.1				[illegible]
tons	22,900		2.3	6.5	11.1	20.2	25.1	15.6	10.1	6.5	1.3	1.3					[illegible]
tons	24,700		3.2	9.7	8.1	17.7	14.5	16.2	6.4	8.1	4.8	8.1	3.2				[illegible]
tons	27,100		6.9	3.9	3.9	9.8	13.7	10.8	15.7	11.8	2.9	13.7	3.9				[illegible]
Over 5 tons	28,200		2.2	4.5	6.2	12.4	11.2	11.2	8.9	11.8	11.8	12.4	5.6	0.6	0.6	0.6	[illegible]

capacity classes are represented by significant numbers of vehicles in each group up to the 30,000-pound limit.

Table 8.—*Classification of all heavy-loaded tractor-semitrailer vehicle combinations according to manufacturer's rated capacity and gross weight*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having gross weights exceeding—							
		21,000 pounds		24,000 pounds		30,000 pounds		40,000 pounds	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
½ tons	57	30	6.1	19	5.4	1	0.6		
tons	47	31	6.3	19	5.4	4	2.5	1	5.0
tons	307	184	37.3	107	30.6	28	17.4		
tons	62	38	7.7	29	8.3	15	9.3	2	10.0
tons	102	77	15.6	63	18.0	36	22.4	4	20.0
Over 5 tons	178	133	27.0	113	32.3	77	47.8	13	65.0
Total	753	493	100.0	350	100.0	161	100.0	20	100.0
Percentage of total loaded vehicles	100	65.5		46.5		21.4		2.7	

Table 9 shows the gross-weight-frequency distribution of all loaded vehicles. Four- and six-wheel single vehicles and semitrailer combinations of all rated capacities are here classified according to gross weight irrespective of type or rated capacity. The most significant indication of this tabulation is the large percentage of all loaded vehicles that exceed 21,000 pounds gross weight. It is shown that 16.5 percent of all loaded vehicles had gross weights in excess of the amount commonly assumed to correspond to a rated capacity of 5 tons.

LIGHT TRUCKS CARRY GREATEST OVERLOADS

It was possible by the methods employed to determine the weight of the load carried by 1,429 single vehicles and 219 semitrailer combinations. Table 10 shows the frequency distribution on the basis of the ratio of load carried to manufacturer's rated capacity for the single vehicles. As previously indicated in the analysis of gross weight, it is here definitely shown that loading in excess of rated capacity is far more prevalent in the case of small trucks than of large ones. On the average, the 1½-ton trucks were found to carry one and two-thirds as much as the recommended load, while the 5-ton trucks averaged just about their rated-capacity load. In extremes, the smaller truck is loaded to 4, 5, and even 6 times its rated capacity; the larger one is seldom loaded more than twice its capacity.

Table 9.—*Frequency distribution of gross weights of loaded vehicles of all classes, percentage of total observations*

[Total number of vehicles observed, 5,592]

Gross weight	Percentage of total number of vehicles	Gross weight	Percentage of total number of vehicles
4,000–6,000 pounds	10.4	28,000–30,000 pounds	1.8
7,000–9,000 pounds	16.0	31,000–33,000 pounds	1.3
10,000–12,000 pounds	16.8	34,000–36,000 pounds	1.0
13,000–15,000 pounds	18.7	37,000–39,000 pounds	
16,000–18,000 pounds	12.1	40,000–42,000 pounds	
19,000–21,000 pounds	9.5	43,000–51,000 pounds	
22,000–24,000 pounds	6.8		
25,000–27,000 pounds	3.9	Total	100.0

In figure 3 is shown a comparison of the numbers of loads of various weights carried by 1½- and 5-ton trucks respectively, on the basis of the total number of each class occurring in the gross weight analysis. It is significant that the 1½-ton truck appears in this graph as the carrier of loads between 6 and 10 tons more numerously than the 5-ton truck.

Table 11 shows an analysis of the loading of semitrailer combinations. Sufficient data could be obtained for only four capacity classes, but the evidence parallels that shown for single vehicles in table 10. Semitrailers of large rated capacity were found in practice to carry loads which, in the average, about equal the recom-

Table 10.—*Frequency distribution of capacity use of loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average ratio	Ratio of carried load to capacity																							Total observations
		0–0.25	0.25–0.50	0.50–0.75	0.75–1.00	1.00–1.25	1.25–1.50	1.50–1.75	1.75–2.00	2.00–2.25	2.25–2.50	2.50–2.75	2.75–3.00	3.00–3.25	3.25–3.50	3.50–3.75	3.75–4.00	4.00–4.25	4.25–4.50	4.50–4.75	4.75–5.00	5.00–5.25	5.25–5.50	[illegible]	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	
½ tons	1.66	9.6	10.1	8.1	7.5	7.6	6.5	7.8	6.2	5.3	5.5	7.1	5.9	3.6	3.9	1.7	0.5	1.3	0.5	0.2	0.4	[illegible]	0.2	0.2	[illegible]
tons	1.56	8.3	8.3	5.8	10.1	12.1	2.6	7.1	9.0	6.4	5.2	8.3	[illegible]	3.9	2.6	1.9	.6								[illegible]
½ tons	1.45	6.0	11.3	6.5	7.2	8.3	10.7	11.3	10.7	12.5	6.5	4.2	2.4	.6		.6	.6								[illegible]
tons	1.32	6.4	7.6	11.6	11.6	10.5	10.5	12.2	5.8	12.2	7.6	1.7		.6		.6									[illegible]
tons	.94	13.6	6.3	16.7	19.8	21.8	12.5	3.1	3.1	3.1															[illegible]

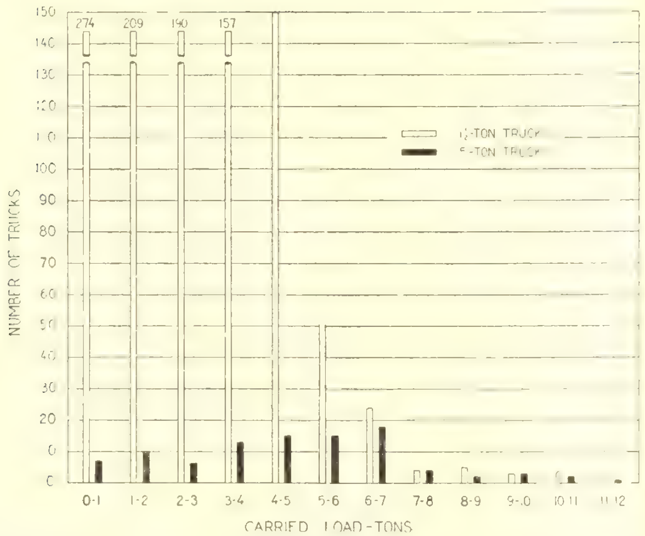

Figure 3.—Trucks of 1½-Ton and 5-Ton Rated Capacity Classed According to Loads Carried.

mended load; the 1½-ton trailers were loaded even more heavily in excess of the rated capacity than the single vehicles of the same rating.

AXLE DISTRIBUTION OF GROSS WEIGHTS OF LOADED VEHICLES DISCUSSED

Tables 12, 13, and 14 show the frequency distribution of the percentage of gross weight of loaded vehicles carried by the rear axles of single trucks, tractors, and semitrailers. From them it may be concluded that, in the case of single vehicles, the weight carried on the rear axle averages approximately three-fourths of the gross load. Vehicles having gross loads less than 10,000 pounds carried an average of only 68 percent on the rear axle. The gross weight groups above 10,000 pounds all had an average of close to 75 percent for weight on the rear axle. Included among these vehicles were many partially loaded trucks, and the low average percentage of load on the rear axle is doubtless due to greater proportionate effect of the engine and the tendency to carry partial loading in the forward part of the truck body. There is a striking spread in the percentages for all gross-weight classes ranging from about 45 to 95 percent.

In the case of tractor-semitrailer combinations, it may be seen that about 45 percent of the entire gross weight of the combination is carried on the rear ends of both tractor and semitrailer, leaving about 10 percent for the front wheels of the tractor.

Table 11.—*Frequency distribution of capacity use of loaded tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average ratio	Ratio of carried load to capacity																										Total observations
		0–0.25	0.25–0.50	0.50–0.75	0.75–1.00	1.00–1.25	1.25–1.50	1.50–1.75	1.75–2.00	2.00–2.25	2.25–2.50	2.50–2.75	2.75–3.00	3.00–3.25	3.25–3.50	3.50–3.75	3.75–4.00	4.00–4.25	4.25–4.50	4.50–4.75	4.75–5.00	5.00–5.25	5.25–5.50	5.50–5.75	5.75–6.00	6.00–6.25	6.25–6.50	
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Number*
1½ tons	3.96	-----	5.6	-----		5.6	5.6		5.6		5.6	5.6		----	5.6	5.6			5.6	5.6	10.9	5.6		16.3	5.6	5.6		18
3 tons	1.94	3.1	5.5	4.7	2.4	9.5	11.8	4.7	7.1	11.0	8.7	11.8	7.1	0.8	6.3	3.1	0.8	1.6										127
5 tons	1.36	4.8	14.2	4.8		23.8	9.5	9.5	23.8		4.8	4.8																21
Over 5 tons	.98	7.5	17.0	11.3	15.1	18.9	18.9	5.6	3.8				1.9															53

Table 12.—*Frequency distribution of percentage of gross weight [1] of loaded single vehicles carried on rear axle, percentage of total observations in each gross-weight class*

Gross weight		Average	Percentage carried on rear axle—												Total observations
			40	45	50	55	60	65	70	75	80	85	90	95	
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
Under 10	1,000 pounds	68.0	0.2	0.2	0.7	4.5	15.3	26.7	28.0	16.2	7.3	1.4	0.3	0.2	1,737
10, under 20	do	75.3	.1	.1	.5	.7	4.3	9.8	16.4	21.4	32.4	12.5	1.6	.2	2,816
20, under 30	do	74.2		.2	.4	.4	2.7	8.1	25.1	35.6	18.8	7.0	1.5	.2	669
30, under 40	do	76.7	1.3	1.3					11.5	35.9	38.4	10.3	1.3		78

[1] In the case of 3-axle, 6-wheel trucks the "gross weight carried on rear axle" is actually carried on 2 axles and 4 wheels.

Table 13.—*Frequency distribution of percentage of gross weight of loaded tractor-semitrailer combinations carried on tractor rear axles, percentage of total observations in each gross-weight class*

Gross weight		Average	Percentage carried on rear axle—											Total observations
			25	30	35	40	45	50	55	60	65	70	75	
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
10, under 20	1,000 pounds	45.2		1.0	5.0	25.8	40.0	18.9	6.2	1.7	0.7	0.7		403
20, under 30	do	44.3	0.1	.9	7.4	24.9	44.8	16.4	4.1	.9	.4		0.1	772
30, under 40	do	41.5	.3	.5	3.8	25.1	48.9	17.1	3.8	.5				398
Over 40	do	43.6			9.3	25.6	51.2	11	2.3					43

Table 14.—*Frequency distribution of percentage of gross weight of loaded tractor-semitrailer combinations carried on semitrailer rear axle,*[1] *percentage of total observations in each gross-weight class*

Gross weight	Average	Percentage carried on rear axle											Total observations
		20	25	30	35	40	45	50	55	60	65	[illegible]	
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
10, under 20 1,000 pounds	39.7	0.7	2.9	14.2	21.0	23.7	23.9	10.2	[illegible]	[illegible]	0.2		[illegible]
20, under 30 do	44.2	.3	1.0	4.2	9.6	20.2	33.6	24.0	5.1	1.1		0.1	[illegible]
30, under 40 do	42.5		.8	1.8	7.8	39.9	36.8	11.1	1.8				[illegible]
Over 40 do	43.2				7.3	39.0	41.5	7.3	4.9				[illegible]

[1] In the case of semitrailers with 2 rear axles, 4 wheels, the "percentage of gross weight carried on rear axle" is actually carried on 2 axles and 4 wheels.

Table 15.—*Frequency distribution of rear-wheel loads of loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average wheel load	Rear wheel load, 1,000 pounds															Total observations
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
	Pounds	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1 ton	2,220	14.6	63.5	12.2	7.3		2.4										[illegible]
1½ tons	3,760	5.3	22.0	21.0	17.5	15.8	14.7	3.2	0.3	0.1	0.1						2,841
2 tons	5,230	.8	7.2	12.6	17.1	16.9	18.8	12.6	10.7	2.7	.6						[illegible]
2½ tons	5,760		3.9	10.6	15.9	16.5	17.4	15.0	9.1	8.5	2.0	0.9	0.2				460
3 tons	6,310	.2	1.5	7.9	11.2	13.9	15.4	20.4	16.4	8.7	3.7	.5			0.2		403
3½ tons	6,550	.8		7.7	10.0	12.4	17.8	16.3	16.3	11.6	4.7	1.6	.8				129
4 tons	6,050		2.7	10.8	5.4	16.2	29.8	13.5	8.1	10.8		2.7					37
5 tons	6,910		.8	4.1	7.8	9.0	16.1	20.6	19.4	17.3	3.7	1.2					243
Over 5 tons	6,050		5.6	8.3	11.1	8.3	27.8	5.5	27.8	2.8	2.8						36

Table 16.—*Frequency distribution of the rear-wheel loads of loaded tractors, percentage of total observations in each capacity class*

Manufacturer's rated capacity[1]	Average wheel load	Rear wheel load, 1,000 pounds											Total observations
		1	2	3	4	5	6	7	8	9	10	11	
	Pounds	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1½ tons	4,690	0.1	3.0	13.8	29.3	25.6	22.3	4.4	1.4	0.1			726
2 tons	5,510		2.1	5.6	17.8	25.8	23.3	16.0	8.0	1.0	0.4		287
2½ tons	6,400		1.0	2.4	12.9	19.1	17.2	16.7	16.3	12.9	1.0	0.5	209
3 tons	6,740			6.0	7.8	9.5	17.2	22.4	19.8	13.8	3.5		116
3½ tons	7,000				7.8	13.7	13.7	17.7	27.4	17.7	2.0		51
4 tons	7,000				11.1	16.7	5.6	22.2	27.7	5.6	11.1		18
5 tons	7,600				2.6	9.2	11.8	17.1	30.3	21.1	7.9		76
Over 5 tons	9,300						12.5		12.5	37.5		37.5	8

[1] Refers to capacity of the semitrailer.

Table 17.—*Frequency distribution of rear-wheel loads of loaded semitrailers, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average wheel load	Rear wheel load, 1,000 pounds													Total observations
		1	2	3	4	5	6	7	8	9	10	11	12	13	
	Pounds	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1½ tons	4,680		14.6	10.9	18.2	23.6	20.0	7.3	3.6	1.8					[illegible]
2 tons	5,130	2.2	4.5	6.7	22.2	24.4	17.8	15.5	4.5	1.1	1.1				45
3 tons	5,010	.3	5.3	9.6	20.9	24.2	24.8	10.9	3.7	.3					[illegible]
4 tons	5,460		6.5	6.5	16.1	17.7	24.2	17.7	9.7	1.6					62
5 tons	5,570	.9	10.0	7.3	10.0	15.4	22.7	16.4	10.0	6.4	.9				[illegible]
Over 5 tons	5,960		4.2	11.3	14.3	13.7	13.1	17.2	14.9	8.3	1.8	0.6		0.6	[illegible]

Similar distribution data were also prepared for single vehicles and combinations without segregation into gross weight classes. These are not presented here as they have the same general characteristics as the data given in tables 12, 13, and 14. They show the following averages: For single trucks 72.8 percent; for tractors 44.6 percent; and for semitrailers 42.5 percent.

DATA ON WHEEL LOADS ANALYZED

Tables 15, 16, and 17, and figures 4, 5, and 6, show frequency distributions of rear-wheel loads of single vehicles, tractors, and semitrailers of various rated capacities. Average rear-wheel loads of single vehicles are shown to range from a minimum of 2,220 pounds for trucks of 1-ton rated capacity to a maximum of 6,910 pounds for 5-ton trucks. Again it is found that the loads of the larger vehicles are not as great in relation to those of smaller vehicles as differences in rated capacity would suggest. The average of 6,910 pounds for 5-ton trucks, for example, is only 1.84 times the 3,760-pound average for 1½-ton trucks instead of 3.33 times as it would be if wheel loads were proportional to rated capacity. It is also apparent, particularly in relation to single vehicles (table 15), that the greatest wheel loads are not always found on vehicles of the largest capacity.

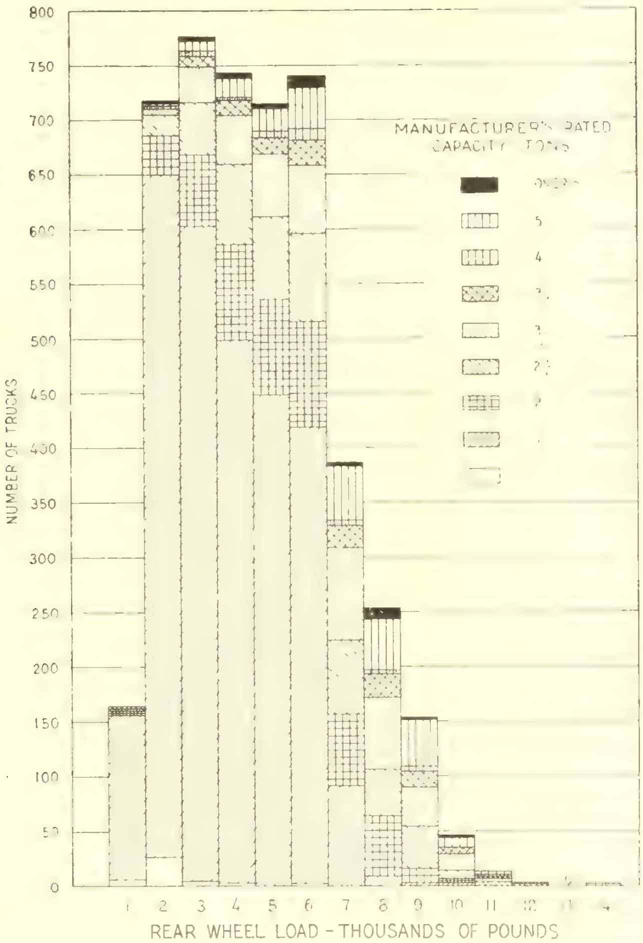

FIGURE 4. - FREQUENCY DISTRIBUTION OF REAR-WHEEL LOADS FOR LOADED SINGLE VEHICLES.

TABLE 18.—*Classification of all loaded single vehicles with heavy wheel loads according to manufacturer's rated capacity and rear-wheel loads*

Manufacturer's rated capacity	Total all loaded vehicles	Rear-wheel loads exceeding—							
		7,000 pounds		8,000 pounds		9,000 pounds		10,000 pounds	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1 ton	41								
1½ tons	2,841	13	2.8	4	1.9	2	3.3		
2 tons	515	72	15.5	17	8.0	3	5.0		
2½ tons	460	95	20.4	53	25.0	14	23.3	5	33.3
3 tons	403	119	25.6	53	25.0	18	30.0	3	20.0
3½ tons	129	45	9.7	24	11.3	9	15.0	3	20.0
4 tons	37	8	1.7	5	2.4	1	1.7	1	6.7
5 tons	243	101	21.7	54	25.5	12	20.0	3	20.0
Over 5 tons	36	12	2.6	2	.9	1	1.7		
Total	4,705	465	100.0	212	100.0	60	100.0	15	100.0
Percentage of total loaded vehicles	100.0	9.9		4.5		1.3		0.3	

In table 18 rear-wheel loads exceeding certain limits are classified according to the rated capacity of the vehicles on which they were observed. The limits chosen were 7,000, 8,000, 9,000, and 10,000 pounds. It is shown that of 4,705 loaded vehicles observed, only 465—less than 10 percent—had rear-wheel loads in excess of 7,000 pounds. Of these 465 vehicles only 113 or less than 25 percent were of 5 tons rated capacity or larger, and 180 or nearly 39 percent were of 2½ tons capacity or smaller.

Vehicles with wheel loads exceeding 8,000 pounds numbered only 212 or 4.5 percent of the total of 4,705 vehicles observed and again the number of vehicles rated at 5 tons or more was less than the number of 2½-ton and smaller vehicles. Sixty or 1.3 percent of the total number of vehicles had wheel loads exceeding 9,000 pounds, and only 15 or about 0.3 percent had wheel loads greater than 10,000 pounds. In these two groups, as in the larger groups with wheel loads above 7,000 and 8,000 pounds, vehicles of the larger capacities were not the most numerous but were, on the contrary, exceeded in number by vehicles of 2½-tons capacity and smaller.

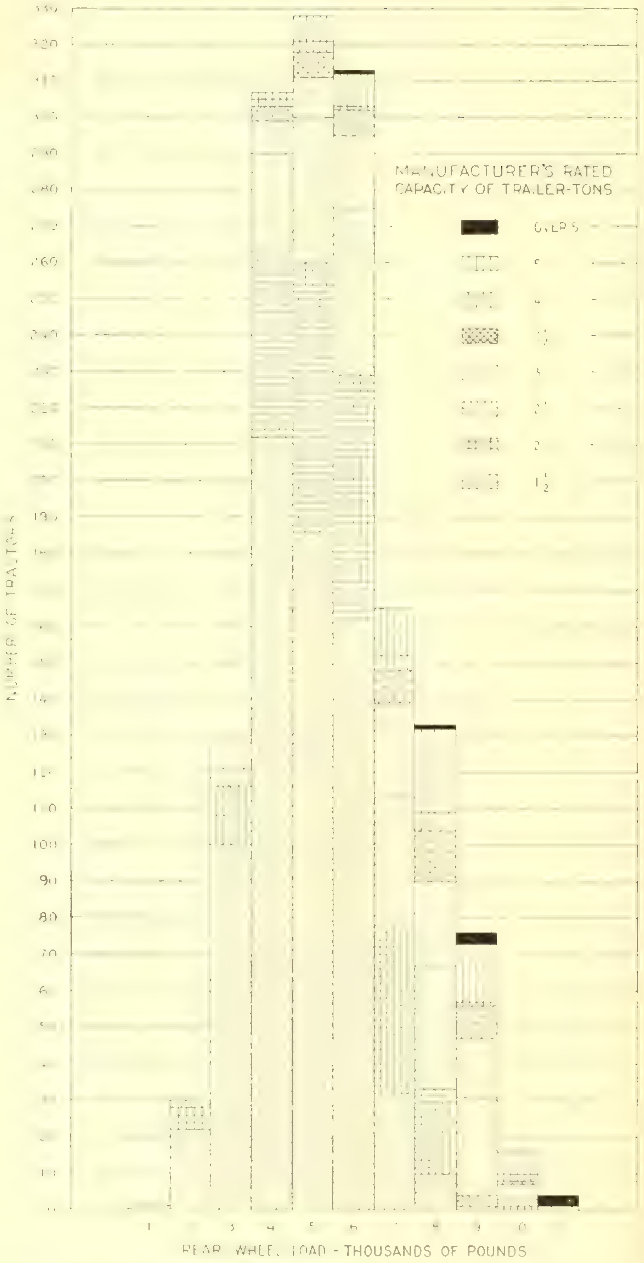

FIGURE 5. -FREQUENCY DISTRIBUTION OF REAR-WHEEL LOADS OF LOADED TRACTORS.

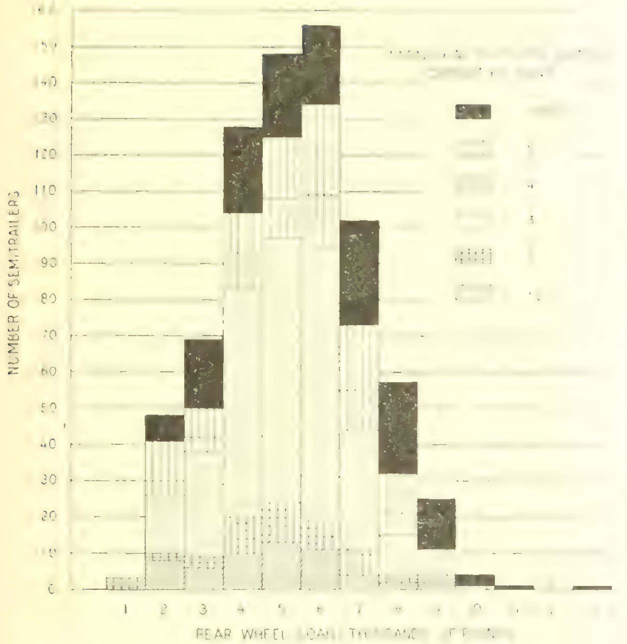

FIGURE 6. FREQUENCY DISTRIBUTION OF REAR-WHEEL LOADS OF LOADED SEMITRAILERS.

TABLE 19.—*Classification of all loaded tractors with heavy wheel loads according to manufacturer's rated capacity and rear-wheel loads*

Manufacturer's rated capacity	Total all loaded vehicles	Rear-wheel loads exceeding—							
		7,000 pounds		8,000 pounds		9,000 pounds		10,000 pounds	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1½ tons	726	11	4.8	1	1.0				
2 tons	287	27	11.8	4	4.2	1	5.0		
2½ tons	209	64	27.9	30	31.3	3	15.0	1	25.0
3 tons	116	43	18.8	20	20.8	4	20.0		
3½ tons	51	24	10.5	10	10.4	1	5.0		
4 tons	18	8	3.5	3	3.1	2	10.0		
5 tons	76	45	19.6	22	22.9	6	30.0		
Over 5 tons	8	7	3.1	6	6.3	3	15.0	3	75.0
Total	1,491	229	100.0	96	100.0	20	100.0	4	100.0
Percentage of total loaded vehicles	100.0	15.4		6.4		1.3		0.3	

In tables 19 and 20, the numbers of loaded tractors and semitrailers, respectively, with rear-wheel loads exceeding the several limits are shown to be approximately as numerous in relation to the totals of such vehicles as were the single vehicles similarly loaded. The tables show, however, that the heavier wheel loads on tractors and semitrailers are more frequently found on combinations of the larger capacities.

TIRE CAPACITY NOT EXCEEDED TO SAME EXTENT AS VEHICLE CAPACITY

In table 21 is shown the frequency distribution of the ratio of actual tire loads to the manufacturer's rated carrying capacity of the tires. Again the tendency for the smaller vehicles to carry loads out of proportion to their capacity is evident in the more frequent overloading of the smaller sizes of tires commonly found on such vehicles. It is to be remarked, however, that the tires are not as greatly overloaded as the vehicles, a fact that is doubtless due to the use of oversized tires on many of the smaller vehicles. Whereas, in extreme cases, 1½-ton trucks were found to carry loads up to six times their rated capacity and more, the extreme overloading of the smallest class of tires did not exceed 2.75 times the rated load of the tires. In the case of the largest tires—those rated at more than 4,000 pounds—the extreme overload observed was only 1.5 times rated capacity, and the number of loads in excess of rated capacity was only about 6 percent of the total.

TABLE 20.—*Classification of all loaded semitrailers with heavy rear-wheel loads according to manufacturer's rated capacity and rear-wheel load*

Manufacturer's rated capacity	Total all loaded vehicles	Rear-wheel loads exceeding—							
		7,000 pounds		8,000 pounds		[illegible] pounds		[illegible]	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1½ tons	[illegible]	[illegible]	3.4	[illegible]					
2 tons	[illegible]	[illegible]	[illegible]	1	3.2				
3 tons	302	[illegible]	[illegible]	1					
4 tons	62	7	8.0						
5 tons	[illegible]	[illegible]	[illegible]	[illegible]	25.8	[illegible]	[illegible]		
Over 5 tons	[illegible]	11	50.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	100.0	[illegible]	[illegible]	2	[illegible]
Percentage of total loaded vehicles	[illegible]	11.9		4.2		[illegible]			

The data presented in table 21 relate to both high-pressure and low-pressure tires indiscriminately. Similar distributions were made for the two classes separately, but as they were very similar to the distribution of the combined groups they are not included in this report.

VALUE OF C IN GROSS-WEIGHT FORMULA DISCUSSED

For the purpose of limiting the gross weight of vehicles and combinations of vehicles the American Association of State Highway Officials has recommended use of the formula, $W = C(L + 40)$, in which W is the gross weight, C a coefficient, and L the length in feet between the centers of the extreme forward and rear axles of the vehicle or combination. The association recommended a value of 700 as the lowest value of C to be adopted as a limit in any State.

It has been definitely determined that limitation of gross weight is not needed as a measure of pavement or road surface protection. Tests have shown that the stress in rigid pavements caused by vehicular loads is a function of the wheel load rather than the gross load. If axles are spaced no closer than 3 feet between centers, it has been determined that the maximum stress caused by the combined wheel loads does not exceed that caused by each wheel load separately. As spacing closer than 3 feet is impracticable, the maximum wheel load of vehicles is the critical factor in design of pavements; and it is wheel load rather than gross load that must be limited for pavement protection.

On bridges the effects of loading are different. All wheel loads of a vehicle or combination of vehicles that can come upon the structure at one time are effective in producing stress, and the stress produced increases with the sum of the loads applied within a given length. For bridge protection, therefore, limitation of wheel load is not sufficient; limitation of gross load is also required. But the form of limitation to be adopted should give proper recognition to the length over which the load is applied. The formula recommended by the American Association of State Highway Officials is of that character; and the value of $C = 700$, recommended as the

Table 21.—*Frequency distribution of capacity use of tires on loaded vehicles, percentage of total observations in each capacity class*

[High-pressure and low-pressure tires combined]

Manufacturer's rated capacity of tires	Average ratio	Ratio of total load on tire to tire capacity											Total observations
		0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1-2 1,000 pounds	1.09	0.4	10.3	20.4	23.4	22.8	15.2	4.4	2.2	0.7	0.1	0.1	2,023
2-3 do	1.07	1.0	10.1	17.6	25.2	26.5	16.8	2.1	.5	.1	.1	......	4,169
3-4 do	.93	1.6	13.1	23.9	38.2	20.0	2.7	.4	.1	......	......	......	1,867
Over 4 do	.81	3.6	19.0	37.6	33.6	4.4	1.8	......	......	......	......	......	225

lowest limit to be adopted, has been found to give, for vehicles and combinations commonly employed, values of the gross load, *W*, that do not unduly overstress bridges designed for the association's standard *H*–15 loading.

Heretofore, determinations of the value of *C* corresponding to various types and combinations of vehicles have been based upon assumptions of probable or maximum permissible wheel loads. In this study values of *C* have been determined for vehicles of various types and sizes, as actually loaded, and frequency distributions of these values for single vehicles and for tractor-semitrailer combinations are given in table 22.

To understand the significance of the values of *C* in table 22, it is necessary to keep in mind that the gross-load limit derived from the formula is an upper limit normally associated with fully loaded or overloaded vehicles of the high-capacity classes. The large percentage of small values of *C* shown in the table is due to the inclusion of low-capacity vehicles and vehicles partly loaded, and these would rarely be affected by a gross-load limitation. Also, it is intended that the gross-load limit given by the formula be used in conjunction with an axle-load or wheel-load limit. In nearly all cases of 4-wheel trucks, the limit on axle or wheel load, not the gross-load formula, will control the gross load.

Table 22.—*Frequency distribution of values of C in the gross-load formula, percentage of total observations*

[Loaded vehicles only]

Group	Total observations	Value of *C*							
		Under 100	100 to 200	200 to 300	300 to 400	400 to 500	500 to 600	600 to 700	Over 700
	Number	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Single vehicles	4,956	5.9	33.6	36.1	17.1	5.5	1.1	0.5	0.2
Tractor - semitrailer combinations	1,551	.1	5.2	23.1	35.4	23.6	11.4	1.1	.1

In view of these circumstances it is interesting to observe that only 0.2 percent of all observed single vehicles and 0.1 percent of all semitrailer combinations had gross weights corresponding to values of *C* above 700. For single vehicles the highest value was 770; but, discarding the 50 highest values (1 percent of the total observed number) the maximum is reduced to 550. For semitrailer combinations the highest observed value was 750, a maximum that would be lowered to 560 by elimination of the highest 1 percent of observed values.

Of the 4,956 single vehicles observed only 10 had gross weights and wheel-base lengths corresponding to values of *C* in excess of 700, the value recommended by the American Association of State Highway Officials as the lowest to be adopted as a limit in any State. Of these 10 trucks, 8 were definitely allocable to manufacturer's rated capacity classes, 2 to the 5-ton class, and 6 to the over-5-ton class. All of these vehicles were 6-wheel vehicles and were the property of a single owner. For trucks of large rated capacity, they had very short wheel bases, ranging from 14 to 15 feet. All were used in the local delivery of crushed stone from a nearby quarry. As they were all 6-wheel vehicles and their wheel loads did not in any case exceed 9,000 pounds they would not have been excluded by wheel-load limitations such as have been recommended by the American Association of State Highway Officials.

Twenty-five of the single vehicles had gross weights and lengths of wheel base resulting in values of *C* over 600 and not more than 700. Of these, 17 could be definitely allocated to rated-capacity classes, as follows: 2½-ton capacity, 2; 3-ton capacity, 1; 3½-ton capacity, 3; 4-ton capacity, 1; 5-ton capacity, 7; over 5-ton capacity, 3.

Of the 1,551 tractor-semitrailer combinations observed only one had gross weight and length resulting in a value of *C* over 700. This was the heaviest combination observed during the study. Its gross weight was 51,500 pounds and the distance, *L*, between its foremost and rearmost axles was 28.9 feet.

Values of *C* between 600 and 700 were found to correspond to 17 semitrailer combinations of which only 5 were classifiable by capacity, one in the 5-ton and the other 4 in the over-5-ton group.

WEIGHTS OF EMPTY VEHICLES AND RATED CAPACITY COMPARED

It is sometimes necessary to know average and extreme weights of empty vehicles of the several capacity classes. It is difficult to obtain this information from manufacturer's records because the weight of the assembled empty vehicle depends upon the type of body used. The manufacturer of the vehicle generally lists the chassis weights only. It has been a common assumption that there is an approximate equality between the weight of single empty vehicles and their rated carrying capacity. The average and distributed weights of empty vehicles of the several classes as observed in this investigation, given in table 23, will show how far from correct this assumption is. Similar data for semitrailer combinations are given in table 24.

CAPACITY OF TRUCK NO INDICATION OF OVER-ALL WIDTH

In the absence of precise information the assertion has been made that motor trucks of the larger capacity classes are commonly wider than those of smaller capacity and consequently require a greater width of pavement for their accommodation. Factors other than the width of the vehicles themselves bear upon the question of pavement width required, including the speed of the vehicles and the driving habits of their operators.

TABLE 23.—*Frequency distribution of the weights of empty single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average empty weight	Weight empty, 1,000 pounds													Total observations
		2	4	6	8	10	12	14	16	18	20	[illegible]	[illegible]	[illegible]	
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
1½ tons	5,690	1.8	23.8	65.3	7.6	1.1	0.4								[illegible]
2 tons	7,690		[illegible]	34.1	[illegible]	14.0	2.3		[illegible]						[illegible]
2½ tons	10,010			8.2	[illegible]	36.9	17.1	6.2	1.9	[illegible]	[illegible]				[illegible]
3 tons	10,720			2.6	[illegible]	39.4	25.5	5.7	4.4	2.2	.4				[illegible]
3½ tons	12,060			3.0	[illegible]	17.9	46.2	19.4	[illegible]	[illegible]					[illegible]
5 tons	14,150			1.0	3.8	7.7	33.6	21.1	11.5	10.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 24.—*Frequency distribution of the weights of empty tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average empty weight	Weight empty, 1,000 pounds											Total observations
		6	8	10	12	14	16	18	[illegible]	[illegible]	24	26	
	Pounds	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
3 tons	10,890	0.8	[illegible]	37.3	31.4	4.0	5.5	[illegible]		1.6			[illegible]
5 tons	13,270		15.1	39.4	9.1	3.0	9.1	9.1	6.1	[illegible]		[illegible]	[illegible]
Over 5 tons	14,320		2.6	15.8	19.7	17.1	22.4	14.5	7.9				[illegible]

TABLE 25.—*Frequency distribution of the over-all widths of loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average width	Over-all width in feet																					Total observations
		5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0	
	Feet	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Number*
1½ tons	7.0	0.1	0.3	0.7	2.2	2.6	2.7	3.6	4.4	7.6	12.6	12.1	12.5	17.0	10.8	5.7	3.6	0.7	[illegible]	[illegible]	[illegible]		[illegible]
2 tons	7.4				.8		.8	1.1	.9	3.0	6.9	11.4	15.4	12.0	[illegible]	14.4	8.3	2.4	.6	.6	.6	[illegible]	533
2½ tons	7.5				.2	.2	.4	.6	1.1	2.1	[illegible]	7.9	14.1	12.9	[illegible]	16.9	[illegible]	[illegible]	2.1	.9	[illegible]		[illegible]
3 tons	7.7							.2	.2	.5	.7	2.9	4.3	11.2	[illegible]	[illegible]	23.0	[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]
3½ tons	7.7								.7		1.5	1.5	5.2	12.0	[illegible]	[illegible]	25.4	[illegible]	3.7				[illegible]
5 tons	7.9							.4			.4	.4	2.4	[illegible]	12.1	23.0	36.3	10.9	[illegible]	[illegible]	[illegible]	[illegible]	248

TABLE 26.—*Frequency distribution of the over-all widths of loaded tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average width	Over-all width in feet												Total observations
		6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	
	Feet	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
1½ tons	7.5			1.8	3.6	12.8	23.7	[illegible]	[illegible]	7.3				[illegible]
2 tons	7.7					4.7	[illegible]	27.9	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
3 tons	7.7	0.3	0.6	1.6	[illegible]	[illegible]	16.1	31.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4 tons	7.7				4.8	[illegible]	11.3	[illegible]	14.5	21.0	[illegible]	[illegible]		[illegible]
5 tons	7.8			1.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
Over 5 tons	7.9	.6		.6	[illegible]	[illegible]	5.1	11.8	21.3	[illegible]	[illegible]	1.1	[illegible]	[illegible]

To the extent that width of the vehicle and its load influence the decision, some light is thrown upon the question by the classifications of over-all widths of observed single vehicles and combinations given in tables 25 and 26, respectively. Figures 7 and 8 are presented to sharpen the comparison between the 1½-ton and 5-ton classes. In the former it will be seen that the 1½-ton trucks were more numerous than the 5-ton vehicles in each width class up to and including the legal limit, 8 feet. Among the law-violating single vehicles the 5-ton trucks are slightly more numerous, and a single 5-ton truck 9 feet wide exceeds the 8.8-foot width of the widest 1½-ton truck.

Among semitrailers there is greater difference between the widths of vehicles of the two capacity classes, as shown in figure 7. No 1½-ton semitrailer combination was observed with over-all width in excess of 8 feet; and the widest 5-ton combination observed was only 8.4 feet wide.

Tables 27 and 28 show for single vehicles and semitrailer combinations, respectively, the number of units observed in excess of certain widths. Table 27 shows that 64.5 percent of all single vehicles observed had over-all widths in excess of 7 feet and nearly 50 percent of the wider vehicles were 1½-ton trucks. Only 1.6 percent of the total number of vehicles were over 8 feet in width and nearly a fourth of this group were of 5-ton capacity, but a greater number were of the 1½ and 2-ton capacities. Less than 1 percent of all the vehicles were more than 8½ feet in width and among them all capacity classes were represented with little difference in number, those of the 1½-ton class still exceeding the 5-ton trucks.

Table 28, similarly reviewing the width data for semitrailer combinations, shows that 96.3 percent of all combinations were more than 7 feet wide; [illegible] percent were more than 8 feet; and only [illegible] percent were wider than 8½ feet. Among these wide vehicles the [illegible]-ton

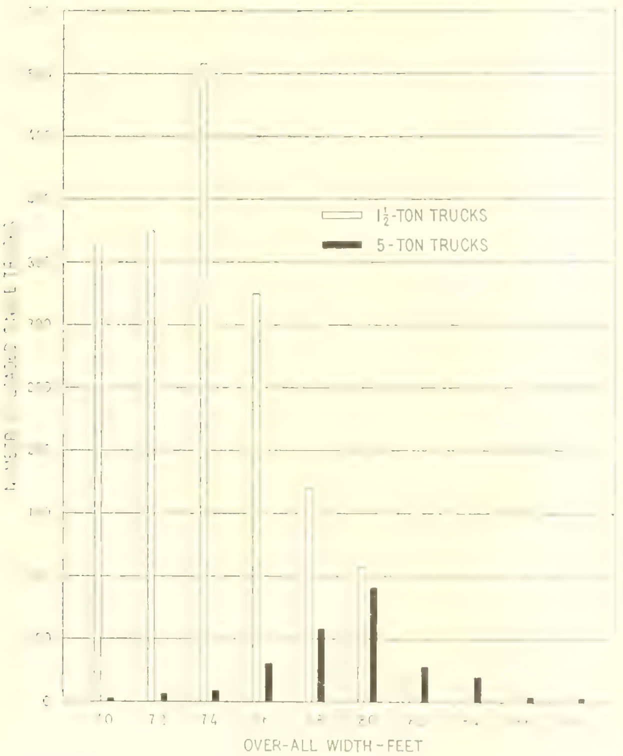

Figure 7.—Comparison of Numbers of Loaded 1½-Ton and 5-Ton Trucks (Rated Capacity) of Various Over-All Widths.

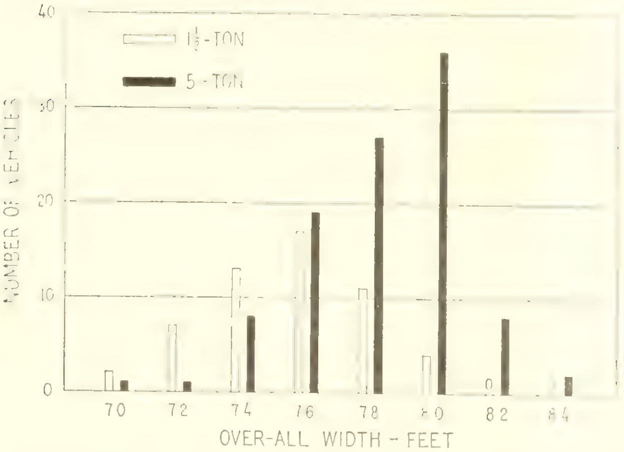

Figure 8.—Comparison of Numbers of Loaded 1½-Ton and 5-Ton Tractor-Semitrailer Combinations (Rated Capacity of Semitrailer) of Various Over-All Widths.

size was not so strongly represented as among the single vehicles, but the several classes from 3-tons to over 5-tons capacity were represented with little distinction.

Table 27.—*Classification of all wide single vehicles according to manufacturer's rated capacity and over-all width*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all widths exceeding—					
		7 feet		8 feet		8½ feet	
	Number	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1½ tons	2,992	1,528	49.5	44	19.9	11	27.5
2 tons	533	400	13.0	23	10.4	7	17.5
2½ tons	468	389	12.6	37	16.8	6	15.0
3 tons	413	394	12.8	46	20.8	8	20.0
3½ tons	134	129	4.2	17	7.7		
5 tons	248	245	7.9	54	24.4	8	20.0
Total	4,788	3,085	100.0	221	100.0	40	100.0
Percentage of total loaded vehicles	100.0	64.5		4.6		0.8	

Table 28.—*Classification of all wide tractor-semitrailer vehicle combinations according to manufacturer's rated capacity and over-all width*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all widths exceeding—					
		7 feet		8 feet		8½ feet	
	Number	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
1½ tons	55	52	7.2				
2 tons	43	43	5.9	2	2.8		
3 tons	310	293	40.5	28	39.4	1	50.0
4 tons	62	59	8.2	9	12.7		
5 tons	103	101	14.0	10	14.1		
Over 5 tons	178	175	24.2	22	31.0	1	50.0
Total	751	723	100.0	71	100.0	2	100.0
Percentage of total loaded vehicles	100.0	96.3		9.5		0.3	

DATA ON HEIGHTS OF LOADED VEHICLES DISCUSSED

Tables 29, 30, 31, and 32 show the distribution of loaded vehicles according to over-all height in a manner corresponding to the previous analysis of width. The average height of the 1½-ton class is shown to be about one foot less than the average height of all trucks of other capacity classes. This is due to the presence in the smaller capacity group of large numbers of low trucks and not to the absence in that group of high vehicles. As shown by table 31, over 56 percent of all single trucks higher than 11 feet were of 1½-tons capacity and so likewise were 63 percent of all trucks over 12 feet in height. The observations included only 3 trucks over 12½ feet high and 2 of these were of 1½-tons capacity.

Comparison of tables 31 and 32 shows that the number of semitrailer combinations of the greater heights was a larger proportion of the total than in the case of single vehicles; and again, as in the matter of width, the small-capacity semitrailer is less numerously represented than the small-capacity truck among the extremely high vehicles.

Figures 9 and 10 show graphically the composition by capacity classes of the numbers of trucks and semitrailer combinations of several of the greater-height groups.

OVER-ALL LENGTHS OF VEHICLES REPORTED

Tables 33, 34, 35, and 36 contain analyses of the over-all lengths of single vehicles and semitrailer combinations similar to those previously presented with regard to other characteristics of the vehicles.

The largest single vehicle observed, the capacity of which could be definitely determined, was 35 feet long. Four larger vehicles were measured, the largest 38 feet long, but these were of indeterminate rated capacity. Of the single vehicles of determinable capacity only 8 exceeded 33 feet in over-all length and 121, or 2.6 percent of the total number observed, exceeded 30 feet. In this connection it is desirable to emphasize that the length recorded was the over-all length of vehicle and load. It included the bumpers and projections of the load if any existed.

The longest semitrailer combination of determinable capacity was 52 feet long. Three that could not be classified by capacity were longer, the longest being 59 feet in length. Only 1 of the 728 semitrailer combi-

TABLE 29.—*Frequency distribution of the over-all heights of loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average height	Over-all height in feet															Total observations
		6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	
	Feet	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1½ tons	8.4	2.2	9.8	13.0	10.6	10.8	12.4	14.7	11.0	6.6	3.6	2.2	1.5	1.0	[illegible]	0.1	[illegible]
2 tons	9.0	.7	1.7	12.4	5.4	9.5	7.8	12.4	16.8	16.7	8.7	1.5	1.7	1.7	[illegible]		[illegible]
2½ tons	9.3		.9	5.4	4.9	12.9	8.1	9.2	17.2	20.0	11.8	[illegible]	.9	[illegible]	.4		[illegible]
3 tons	9.4		1.0	4.1	9.7	8.7	6.8	10.2	13.4	17.4	18.8	4.8	2.9	1.0	1.0	[illegible]	[illegible]
3½ tons	9.7			1.5	5.4	7.8	11.6	3.1	11.6	21.7	21.0	[illegible]	4.7	[illegible]	.8		129
5 tons	9.4	.4		.8	3.2	13.4	16.9	8.3	9.7	23.2	17.4	7.1	1.6				[illegible]

TABLE 30.—*Frequency distribution of the over-all heights of loaded tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average height	Over-all height in feet—															Total observations
		6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	
	Feet	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1½ tons	9.6	1.8	1.8	5.5	5.5	9.1	9.1	3.6	14.6	12.7	12.7	10.9	3.6	7.3	1.8		[illegible]
2 tons	10.2	2.6		2.6		2.6			15.4	28.1	17.9	17.9	2.6	5.1	2.6	2.6	[illegible]
3 tons	10.2	.3		3.0	3.4	4.4	2.0	5.8	9.9	17.3	18.7	15.9	12.2	5.8	3.0	.3	295
4 tons	10.7						1.5	4.5	13.4	13.4	13.4	23.9	16.4	10.5	1.5	1.5	[illegible]
5 tons	10.6			1.0		1.0		3.9	1.0	22.6	29.4	27.6	12.7	2.9			102
Over 5 tons	10.6			.6	1.1	.6	3.4	1.7	2.8	12.4	30.8	31.4	11.8	2.8	.6		[illegible]

TABLE 31.—*Classification of all high, single vehicles according to manufacturer's rated capacity and over-all height*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all heights exceeding—					
		11 feet		12 feet		12½ feet	
	Number	Number	Percent	Number	Percent	Number	Percent
1½ tons	2,985	91	56.5	17	63.0	2	66.7
2 tons	539	20	12.4	2	7.4		
2½ tons	466	16	9.9	2	7.4		
3 tons	412	21	13.1	5	18.5	1	33.3
3½ tons	129	9	5.6	1	3.7		
5 tons	254	4	2.5				
Total	4,785	161	100.0	27	100.0	3	100.0
Percentage of total loaded vehicles	100.0	3.4		0.6		0.1	

TABLE 32.—*Classification of all high loaded tractor-semitrailer vehicle combinations according to manufacturer's rated capacity and over-all height*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all heights exceeding—					
		11 feet		12 feet		12½ feet	
	Number	Number	Percent	Number	Percent	Number	Percent
1½ tons	55	7	5.1	1	6.2		
2 tons	39	5	3.6	2	12.5	1	33.3
3 tons	295	63	45.6	10	62.5	1	33.3
4 tons	67	20	14.5	2	12.5	1	33.4
5 tons	102	16	11.6				
Over 5 tons	178	27	19.6	1	6.3		
Total	736	138	100.0	16	100.0	3	100.0
Percentage of total loaded vehicles	100.0	18.8		2.2		0.4	

TABLE 33.—*Frequency distribution of the over-all lengths of loaded single vehicles, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average length	Over-all length in feet																					Total observations
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
	Feet	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Number
1½ tons	20.8	2.0	2.7	5.6	7.9	4.6	11.0	36.4	13.6	5.3	3.5	2.8	1.9	1.0	0.4	0.5	0.3	0.2	0.3				[illegible]
2 tons	23.5		.2	1.5	1.9	2.1	3.7	11.6	14.4	11.1	19.4	13.1	6.5	3.6	3.0	1.9	1.3	.7	.7				[illegible]
2½ tons	24.0	.2	.4	.6	2.4	4.3	5.4	7.3	12.3	12.1	14.4	10.6	10.8	5.2	5.4	3.2	2.8	.9	1.7				[illegible]
3 tons	25.8		.2	.2	1.2	1.7	2.0	2.5	4.9	6.6	11.8	14.2	15.2	12.6	9.6	4.7	3.2	4.2	2.5	2.5	0.2		407
3½ tons	26.3			.8	3.1	2.4	4.7	1.6	4.7	4.7	9.4	10.3	11.8	8.8	9.4	1.7	6.3	5.5	6.3	3.1		2.4	[illegible]
5 tons	25.6			1.2	.4	1.6	3.6	3.1	2.0	12.6	18.6	14.3	7.1	9.7	4.3	7.9	3.5	5.1	2.4	1.2	.4		253

TABLE 34.—*Frequency distribution of the over-all lengths of loaded tractor-semitrailer combinations, percentage of total observations in each capacity class*

Manufacturer's rated capacity	Average length	Over-all length in feet														Total observations
		26	28	30	32	34	36	38	40	42	44	46	48	50	52	
	Feet	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Number
1½ tons	33.2	1.6	8.1	16.1	30.6	17.8	8.1	12.9	1.6	1.6	1.6					[illegible]
2 tons	33.5	2.3	13.6	20.5	20.4	11.4	6.8	9.1	4.5	6.8	4.5					[illegible]
3 tons	33.0	3.4	10.0	21.0	21.6	13.8	11.0	7.5	2.7	1.4	5.2	[illegible]	[illegible]			[illegible]
4 tons	36.7		4.8	12.7	12.7	7.9	14.3	19.1	6.3	11.1	3.2	6.3				63
5 tons	33.7	7.2	16.5	8.2	9.3	[illegible]	23.7	10.3	3.1	[illegible]	2.1	[illegible]				[illegible]
Over 5 tons	34.3	.6	4.1	8.8	21.0	[illegible]	15.2	6.4	4.1	1.2	2.3	1.2	[illegible]			171

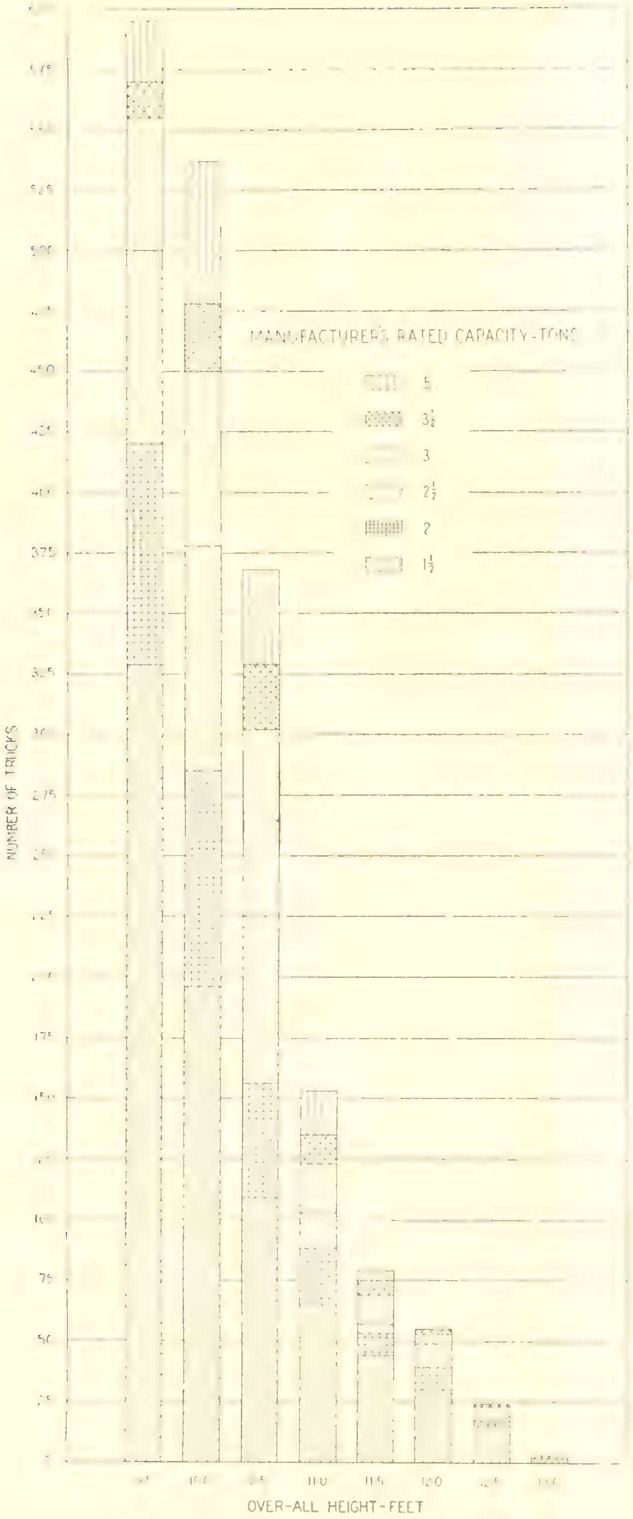

FIGURE 9.—LOADED TRUCKS IN HEIGHT CLASSIFICATION FROM 9½ TO 13 FEET GROUPED ACCORDING TO RATED CAPACITY.

nations that could be classified by capacity was more than 50 feet in length. Eighteen, or 2.5 percent of the total, were over 45 feet long; and 63, or 8.7 percent, were over 40 feet in length. More than one-third—253 of the 728 loaded semitrailer combinations classifiable by capacity—were more than 35 feet long over-all.

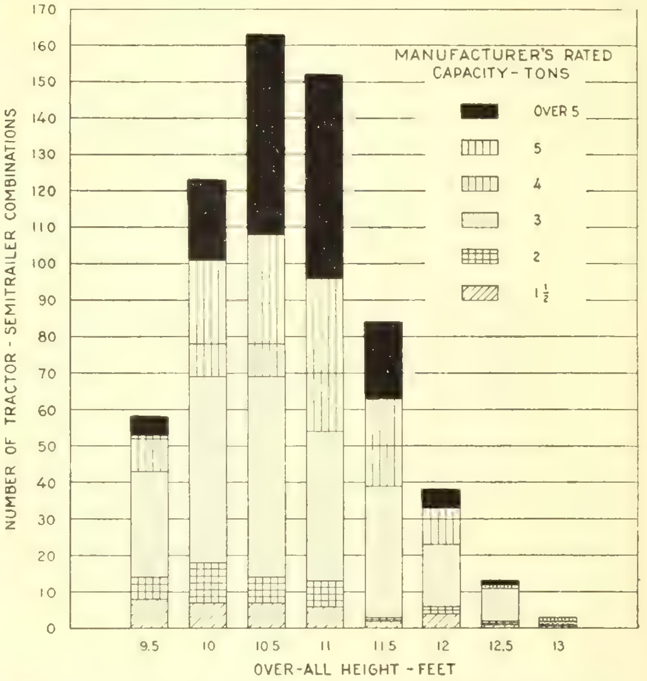

FIGURE 10.—LOADED TRACTOR-SEMITRAILER COMBINATIONS IN HEIGHT CLASSIFICATIONS FROM 9½ TO 13 FEET GROUPED ACCORDING TO RATED CAPACITY.

TABLE 35.—*Classification of all long, loaded, single vehicles according to manufacturer's rated capacity and over-all length*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all lengths exceeding—					
		25 feet		30 feet		33 feet	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1½ tons	2,953	135	17.4	15	12.4		
2 tons	536	95	12.3	8	6.6		
2½ tons	463	139	18.0	12	9.9		
3 tons	407	222	28.7	38	31.4	1	12.5
3½ tons	127	74	9.6	22	18.2	3	37.5
5 tons	253	108	14.0	26	21.5	4	50.0
Total	4,739	773	100.0	121	100.0	8	100.0
Percentage of total loaded vehicles	100.0	16.3		2.6		0.2	

TABLE 36.—*Classification of all long, loaded, tractor-semitrailer vehicle combinations according to manufacturer's rated capacity and over-all length*

Manufacturer's rated capacity	Total all loaded vehicles	Loaded vehicles having over-all lengths exceeding—									
		30 feet		35 feet		40 feet		45 feet		50 feet	
	No.	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*	*No.*	*Pct.*
1½ tons	62	46	8.7	16	6.3	2	3.2				
2 tons	44	28	5.3	14	5.5	5	7.9				
3 tons	291	191	36.0	88	34.8	26	41.3	7	38.9		
4 tons	63	52	9.8	39	15.4	14	22.2	5	27.8		
5 tons	97	66	12.4	42	16.6	6	9.5	2	11.1	1	100.0
Over 5 tons	171	148	27.8	54	21.4	10	15.9	4	22.2		
Total	728	531	100.0	253	100.0	63	100.0	18	100.0	1	100.0
Percentage of total loaded vehicles	100.0	72.9		34.8		8.7		2.5			

As shown by tables 33 and 34, the longest vehicles and combinations were of large and intermediate capacity classes. The largest single vehicles of the 1½-, 2-, and 2½-ton classes were 32 feet long; the longest 1½- and 2-ton semitrailer combinations were 44 feet long.

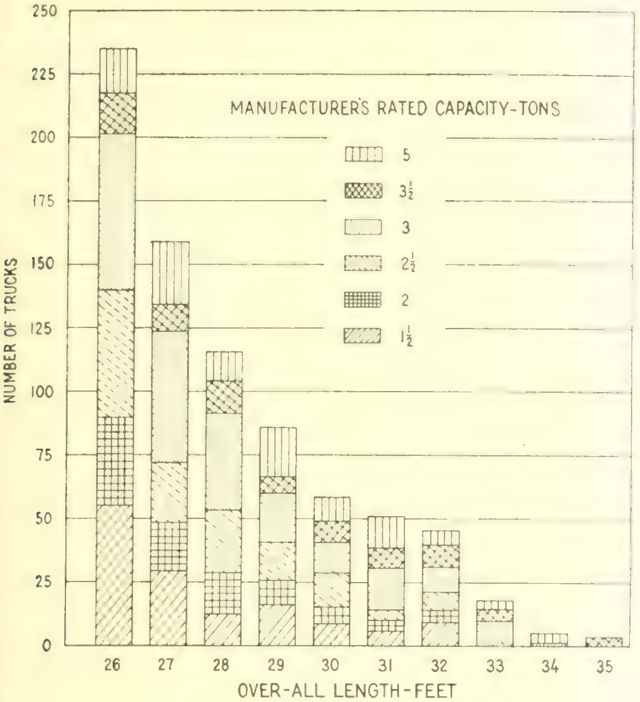

FIGURE 11.—LOADED SINGLE VEHICLES GROUPED ACCORDING TO OVER-ALL LENGTH AND WITHIN GROUPS ACCORDING TO RATED CAPACITY.

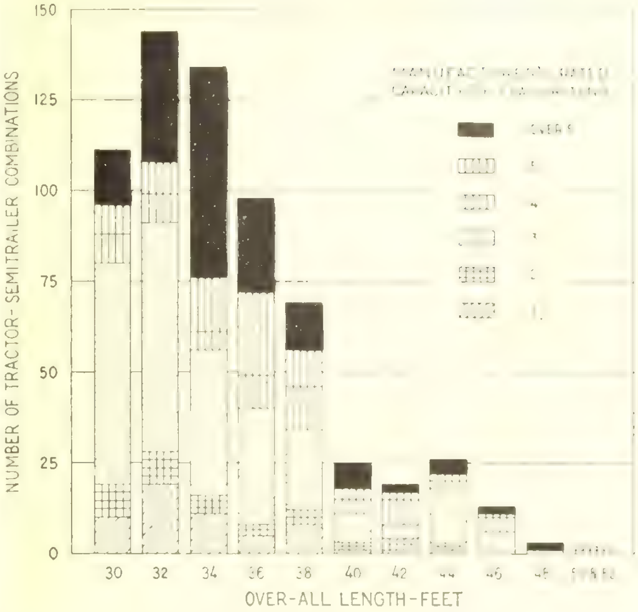

FIGURE 12.—LOADED TRACTOR-SEMITRAILER COMBINATIONS GROUPED ACCORDING TO OVER-ALL LENGTH AND WITHIN GROUPS ACCORDING TO RATED CAPACITY.

TABLE 37.—*Weights and dimensions of combinations that included full trailers*

Combination no.	Type of combination	Manufacturer's rated capacity	Gross weight of combination	Gross weight	Rear axle load	Percentage of gross weight carried on— Truck rear axle	Tractor rear axle	Semi-trailer axle	Full trailer Front axle	Full trailer Rear axle	Tire arrangement [1]	Rear-wheel load	Ratio of tire load to tire capacity	Over-all height	Over-all width	Over-all length	Over-all wheel base	Ratio of over-all wheel base to over-all length	Value of "C" in formula W = C(L+40)	Character of load	Origin and destination
		Tons	*Lbs.*	*Lbs.*	*Lbs.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*		*Lbs.*	*Pct.*	*Feet*	*Feet*	*Feet*	*Feet*				
1	Truck		77,080	38,520	32,140	42					6 D	8,035	101	9.5	7.8	58.7	49.7	1.18	860	Gasoline	Maryland to Delaware
	Full trailer			38,560	25,760				17	33	6 D	6,440	80								
2	Tractor		31,400	15,700	9,240		29				4 D	4,620	59	11.0	7.7	53.0	47.6	1.13	360		Do.
	Semitrailer				8,000			25			2 D	4,000	40								
	Full trailer	5		7,700	3,800				12	12	4 D	1,900	37								
3	Truck	3	39,800	24,425	18,770	47					4 D	9,385	130	9.4	7.1	42.7	38.1	1.12	500	Paper	Maryland to District of Columbia
	Full trailer			15,375	7,330				39	18	4 D	3,665	83								
4	Truck	1½	11,700	9,200	7,150	41					4 S	3,575		10.0	6.4	37.6	31.0	1.11	160	Furniture	New York to Florida
	Full trailer			2,500	1,275				10	11	4 S	638									
5	Truck	2½	36,800	18,500	14,740	40					4 D	7,370	145	11.8	7.7	42.4	37.4	1.13	490	Agricultural products	North Carolina to New York
	Full trailer			18,300	9,000				25	24	4 S	4,500	125								
6	Truck	3½	39,375	25,200	16,450	42					4 D	8,225	105	11.8	7.7	48.8	44.3	1.21	470	Produce	North Carolina to Maryland.
	Full trailer			14,175	6,600				19	17	4 DD	3,300	100								
7	Truck	1½	25,540	15,180	12,370	48					4 D	6,185	149	8.0	7.0	37.8	33.0	1.15	350	Fruit	Florida to Pennsylvania
	Full trailer			10,360	5,300				20	21	4 S	2,150									
8	Tractor	3½	30,600	12,700	8,100		26				4 D	4,050	51	11.0	8.0	53.6	48.8	1.10	340	Freight	Delaware to Maryland
	Semitrailer	10			6,200			20			2 D	3,100	48								
	Fulltrailer	5		11,700	5,300				21	17	4 D	2,650	34								
9	Truck	2½	58,700	38,100	30,300	52					6 D	7,575	97	10.5	7.8	53.3	48.4	1.10	660	Soy beans	Do.
	Full trailer	5		20,600	10,300				18	18	4 DD	5,150	79								
10	Truck	3	39,300	24,000	18,300	47					4 D	9,150	127	9.5	7.2	42.6	38.0	1.12	500	Paper	District of Columbia to Maryland
	Full trailer			15,300	7,500				20	19	4 DD	3,750	85								

[1] The number designates the number of wheels on each unit. The letter indicates arrangement of tires on wheels carried by rear axle. D indicates dual tires and S indicates single tires. On full trailers DD means that wheels on both front and rear axles carry dual tires.

Figures 11 and 12 show graphically the relative numbers of single vehicles and semitrailer combinations of the several capacity classes in each of the larger length groups. It will be observed that single vehicles of low rated capacity were an important part of each length group up to 32 feet—the greatest length observed for such vehicles. In the case of semitrailer combinations, those of the lower rated capacities are an unimportant part of the total above the length of 38 feet.

WEIGHTS AND DIMENSIONS OF FULL-TRAILER COMBINATIONS GIVEN

Only 10 combinations having full trailers were observed during the course of the survey. The weights, dimensions, and other characteristics of these vehicles are given in table 37. In general their characteristics are similar to those of the tractor-semitrailer combinations which have been discussed in detail, but one should be noted particularly as the longest and heaviest combination observed during the period. This combination, with a gross load of 77,000 pounds and a length of 58.7 feet, had a value of C in the gross-load formula recommended by the American Association of State Highway Officials of 860. This is the largest value noted in the period of observation and exceeds the next largest value observed by nearly 100. This combination consisted of a tank truck and a tank trailer and was used to transport gasoline.

REPORT ON TAXATION OF MOTOR VEHICLES IN 1932 AVAILABLE

The full report on the study of motor vehicle taxation in 1932 by the United States Bureau of Public Roads is now available. The survey was begun in 1933 and completed in 1934 and is the broadest in scope yet attempted. The report includes not only State taxes but also Federal excise taxes, county and municipal taxes, personal-property taxes on motor vehicles imposed by State, county, and municipal jurisdictions, and public bridge tolls. The data are analyzed so that the numbers and contributions of various classes of vehicles may be determined.

A digest of the report was published in Public Roads, October 1934. The full report, entitled "The Taxation of Motor Vehicles in 1932", consists of 270 pages and is for sale by the Superintendent of Documents, Government Printing Office, Washington, D. C., for 35 cents. There is no supply for general free distribution. Orders should be sent direct to the Superintendent of Documents at the above address.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF APRIL 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 5,778,739	$ 3,132,239	$ 35,890	312.1	$ 2,566,548	$ 729,230	$ 1,237,976	151.8	$ 78,001	$ 196,641	12.2	$ 8,283	$ 659,414
Arizona	3,878,555	1,338,712	4,552,883	3,697,024	245,934	314.9	1,183,412	160,262	968,606	75.3		65,041	.4	21,269	59,131
Arkansas	3,334,167	1,714,000	3,141,122	2,466,590	150,703	155.7	1,726,430	694,108	821,095	76.0	39,563	495,944	27.9	133,907	246,258
California	7,912,928	3,713,643	9,306,642	6,966,585	2,200	277.6	4,346,155	946,148	2,113,995	132.9		842,490	26.6	195	754,958
Colorado	3,437,265	2,424,504	4,092,855	3,314,321	675,146	192.4	1,973,938	122,944	1,733,560	94.8		4,973			10,825
Connecticut	1,404,213	607,500	797,613	795,279		14.5	1,451,228	608,934	579,726	23.4					27,774
Delaware	877,566	461,697	1,052,958	868,470	177,572	42.0	296,479	8,734	274,891	6.8		5,858		362	3,377
Florida	2,469,370	1,116,600	3,108,167	2,247,168	31,410	117.4	943,790	194,891	698,743	34.1		142,641	3.8	27,310	243,807
Georgia	5,045,592	2,556,745	3,693,105	3,493,273		254.4	2,760,461	1,381,647	1,343,814	143.7	64,972	287,641	23.4	105,700	925,290
Idaho	2,166,858	1,131,910	2,139,228	1,965,578	107,294	186.0	719,704	200,496	506,290	45.8				784	518,326
Illinois	4,442,467	3,060,041	1,994,240	1,941,129	19,269	38.2	3,978,753	2,454,691	1,524,062	66.1	3,000	358,704	3.5	43,647	1,158,005
Indiana	5,018,921	2,816,687	3,296,771	3,215,100		106.3	2,795,719	1,689,012	1,071,492	70.9	77,951	1,630,836	113.7	36,858	114,359
Iowa	5,027,830	2,217,361	4,775,953	4,637,430	54,420	288.6	2,608,914	390,400	1,987,905	137.9		137,324	13.0		37,712
Kansas	5,044,822	2,364,131	5,367,382	4,963,354	266,535	587.3	2,142,297	56,400	2,040,651	166.4		46,945	5.2	25,043	
Kentucky	3,741,005	1,527,324	3,601,224	3,334,508	33,571	244.1	879,836	384,396	419,773	72.2		697,752	32.6	32,701	376,228
Louisiana	2,693,135	1,380,419	1,851,671	1,826,016	19,599	75.4	2,178,364	830,877	833,686	15.8	36,242	287,440	14.7		239,694
Maine	1,567,012	793,644	1,345,616	1,315,837		43.8	802,094	243,876	558,218	13.5	4,618	204,636	6.8	2,681	30,791
Maryland	1,782,263	289,609	808,265	791,495	16,517	15.3	1,001,994	797,232	204,762	21.5				193,536	68,331
Massachusetts	1,101,716	1,632,874	1,423,764	1,030,789		37.4	913,806	52,687	809,298	12.5		181,433	6.9	18,240	642,144
Michigan	6,051,532	3,226,284	4,922,459	4,767,686		225.4	3,546,825	1,250,600	2,281,425	134.3		690,750	37.5	33,247	254,109
Minnesota	4,561,011	2,642,244	5,633,297	4,253,085	1,240,277	891.3	824,609	179,056	613,153	103.7		523,878	70.1	128,870	264,935
Mississippi	3,489,337	2,832,182	4,574,660	2,398,442	187,599	237.1	2,669,310	908,666	1,023,840	144.3	157,543	998,109	64.8	24,687	622,633
Missouri	5,237,532	2,132,426	4,711,323	4,173,675		188.7	2,933,364	989,027	1,723,216	85.8		233,456	8.6	74,830	175,754
Montana	4,463,849	2,714,208	5,923,705	4,429,840	960,838	482.6	1,566,328	4,129	1,493,241	134.9		107,931	18.5	29,879	152,198
Nebraska	3,914,481	1,982,182	5,087,171	3,871,728	54,009	366.8	2,241,220	25,924	1,813,460	100.0	3,918	71,690	7.9	12,912	43,022
Nevada	2,909,387	1,350,356	2,858,941	2,669,138	131,852	272.1	1,216,669	179,532	975,827	150.1	17,734	19,855	2.6	42,982	222,823
New Hampshire	692,119	484,731	638,684	612,389		10.8	524,341	79,730	422,873	12.5		18,673			43,184
New Jersey	3,173,019	951,379	1,777,937	1,758,405		31.6	1,726,150	1,405,336	131,657	18.0		439,718	3.0	9,278	380,004
New Mexico	2,846,648	1,676,769	3,285,054	2,760,948	381,177	317.3	1,005,398	85,700	848,804	76.9		173,173	15.1		273,615
New York	10,465,672	3,748,600	10,617,113	8,715,879	168,930	214.4	8,130,743	1,631,070	3,085,180	142.5		326,100	4.4	118,723	168,390
North Carolina	4,761,147	2,040,068	4,684,107	3,501,810	305,933	584.8	1,472,608	848,161	362,335	160.3	159,106	295,513	21.9	252,069	1,076,287
North Dakota	2,902,224	1,469,484	3,119,028	2,615,891	57,900	1,023.9	505,218	54,095	350,908	208.4	65,172	446,432	223.7	167,066	614,243
Ohio	7,277,758	3,539,256	7,431,032	7,040,880		191.3	3,341,740	93,600	2,922,590	70.4	101,298	26,720	2.2	41,980	589,946
Oklahoma	4,608,399	2,342,590	4,284,045	4,085,173	66,604	304.3	2,311,486	513,197	1,585,774	90.0	10,029	317,624	13.1		372,587
Oregon	3,053,448	1,452,741	3,448,551	2,971,548	144,622	186.0	1,159,167	10,790	1,123,115	57.0	69,800	22,000	1.4	1,310	163,004
Pennsylvania	6,691,194	4,554,082	5,910,420	5,495,190	170,304	124.4	5,489,477	1,143,622	4,126,664	95.1	2,126	56,082	1.4	50,256	201,032
Rhode Island	979,367	474,772	968,005	899,627		20.5	560,592	79,740	464,572	14.3					10,200
South Carolina	2,729,583	940,954	2,346,397	2,258,083	27,818	199.1	809,210	374,583	434,627	71.5	36,876	1,637	2.2	60,041	476,871
South Dakota	3,005,739	1,523,821	2,715,606	2,207,574	46,543	458.5	1,326,697	653,701	646,319	246.6	87,403	740,756	123.8	57,061	90,203
Tennessee	4,240,309	2,105,453	4,653,371	3,950,708	64,152	182.5	1,626,631	249,628	1,280,602	53.3	9,488	213,044	7.5	36,484	547,656
Texas	11,588,643	6,858,253	11,860,198	11,164,929	168,682	1,011.7	4,858,166	336,994	4,333,239	382.2	86,720	1,314,516	106.2		1,041,816
Utah	2,367,205	1,066,345	2,807,441	2,277,220	364,113	237.8	810,926	84,632	514,884	61.7		32,000	3.5	5,353	155,349
Vermont	928,184	466,042	967,516	902,837	28,464	47.9	347,973	10,670	309,279	15.4		113,807	4.2	14,677	14,493
Virginia	3,708,379	1,882,693	3,756,192	3,356,653	170,305	159.3	1,692,244	205,323	1,356,584	66.1	52,625	156,182	19.1	93,779	199,623
Washington	3,057,934	1,553,206	2,806,744	2,587,440	198,794	99.4	1,603,910	435,526	1,007,336	29.5	1,485	209,908	1.2	33,483	137,168
West Virginia	2,013,405	1,140,167	1,930,305	1,851,481	60,891	71.2	659,234	111,669	530,673	23.5	23,589	182,332	5.6	26,666	366,270
Wisconsin	4,697,518	1,751,970	4,287,975	4,115,451	8,236	207.5	1,631,168	491,836	996,098	71.7	182	685,428	24.2	90,049	62,208
Wyoming	2,250,663	1,086,368	2,540,830	2,038,070	337,236	499.3	1,187,179	209,202	951,812	164.7		349,516	68.9	3,391	47,808
District of Columbia															
Hawaii	1,693,344	593,778	419,600	273,974		13.6	1,763,640	1,412,579		26.0				6,791	593,778
TOTALS	185,269,048	94,455,726	183,096,905	156,007,939	7,181,339	12,164.5	94,812,145	26,005,283	57,438,630	4,372.1	1,189,441	14,353,129	1,153.3	2,066,385	15,482,628

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF APRIL 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 1,624,889	$ 1,583,983	$ 39,465	39.4	$ 842,275	$ 657,876	$ 184,399	29.0	$ 131,223	$ 208,328	5.1	$ 16,845	$ 632,768
Arizona	807,982	305,191	644,776	609,690	24,120	13.3	39,104	20,500	13,185	.9	129,322	95,500	.7	48,571	172,386
Arkansas	1,964,534	857,025	1,571,476	1,454,286	17,953	41.1	600,425	395,400	204,475	10.2	101,076	271,224	6.0	13,771	363,374
California	4,213,986	2,219,360	4,060,368	3,459,880	12,000	47.8	2,236,062	739,196	1,190,932	20.5		793,544	4.9	14,910	222,884
Colorado	1,718,633	190,000	1,770,072	1,664,436	13,406	35.9	156,005		156,005	4.1				53,698	20,590
Connecticut	802,407	426,500	809,564	798,075	6,949	10.3	140,239		140,239	1.2		143,909	1.7	4,331	135,403
Delaware	460,409	270,849	513,762	460,282	44,973	7.2	6,570		6,570	.1		38,235	1.8	126	141,072
Florida	1,459,648	561,200	1,727,316	1,398,151	70,889	20.6	31,938		31,938	.6	2,898	157,696	1.4	58,600	240,677
Georgia	2,724,620	1,278,373	1,578,644	1,566,701		59.4	1,231,985	978,037	253,948	26.1		269,915	6.0	179,883	754,511
Idaho	1,197,829	361,126	1,162,534	1,119,507	2,643	19.4	71,867	45,372	26,495	1.9		209,525	.2	32,950	82,463
Illinois	7,476,075	2,515,835	6,004,604	5,757,379		63.5	2,372,581	1,566,225	806,356	11.3	57,163	425,336	3.3	95,308	1,284,144
Indiana	4,287,060	2,136,306	2,959,435	2,860,685		60.3	1,601,321	1,262,896	335,961	18.1	138,381	1,031,047	20.6	25,088	769,298
Iowa	2,614,472	1,311,000	1,377,158	1,291,868	7,085	54.0	1,289,041	721,566	486,115	17.4	1,000	217,735	6.8	39	600,066
Kansas	2,622,401	1,432,949	2,243,006	2,207,201	34,017	39.4	1,730,329	275,108	1,295,065	16.4		103,867	1.7	40,092	
Kentucky	1,967,268	964,478	[illegible]	[illegible]		31.3	841,127	[illegible]	304,699	8.5	30,000	212,124	4.8	5,222	436,754
Louisiana	1,706,577	744,560	734,039	[illegible]	34,048	19.0	[illegible]	922,541	263,091	16.4	82,217	149,761	4.3		297,660
Maine	960,426	490,045	835,547	829,154		16.4	99,446	47,071	52,375	.5	83,948	98,817	2.6	253	338,853
Maryland	891,132	452,515	390,127	384,134		4.1	911,650	98,129		.4	150,828		.5	258,041	452,514
Massachusetts	5,007,199	847,600	2,125,586	2,084,041		13.4	3,126,137	2,876,372	224,789	5.7		51,225	.9	46,787	571,587
Michigan	3,500,638	1,613,142	3,245,466	3,056,216	104,400	38.8	1,635,650	412,750	1,185,000	14.6	14,950	128,000	4.7	16,721	195,742
Minnesota	3,719,143	1,421,494	3,232,379	3,000,538	195,923	108.1	503,754	172,113	323,440	12.2	516,059	[illegible]	5.8	30,433	867,251
Mississippi	1,744,669	354,022	713,564	672,600	27,695	26.1	1,039,885	858,440	135,888	27.2	182,215	75,122	8.7	31,414	115,318
Missouri	4,019,501	1,617,451	2,840,268	2,769,719		51.4	1,297,755	1,105,442	146,476	11.2	23,343	65,197	1.2	120,997	1,405,778
Montana	1,115,962	113,092	1,033,290	1,024,038		33.2	99,549	34,716	40,279	5.2	28,667	31,863	2.9	28,541	40,949
Nebraska	1,957,240	991,091	2,139,593	1,943,547	166,420	37.0	607,903		607,903	10.4		79,919	2.1	13,693	136,849
Nevada	500,051	100,000	479,800	473,901		9.4	57,842		57,842	1.4				26,150	42,158
New Hampshire	740,335	242,366	721,984	668,776	49,851	15.9	131,823	71,559	60,055	3.0					132,460
New Jersey	3,117,921	1,809,500	2,580,387	2,450,104		21.4	1,190,747	641,264	434,690	5.7		208,357	.8	26,553	1,166,453
New Mexico	1,674,158	529,506	1,568,730	1,395,399	173,331	35.3	271,016	194,818	76,198	6.5	3,119			80,822	279,977
New York	8,255,661	3,756,621	7,002,521	6,277,447	299,400	55.9	5,007,781	1,829,357	2,959,290	29.1		143,200	1.3	148,857	354,731
North Carolina	2,380,573	1,210,236	2,200,334	2,091,279	101,308	78.1	590,748	142,205	398,091	15.4	91,217	432,801	12.3	55,872	278,037
North Dakota	1,451,112	734,742	1,020,946	1,013,739		42.9	289,153	202,959	86,194	10.7	210,262	250,251	27.1	24,153	398,296
Ohio	4,335,686	2,359,503	4,507,040	4,017,456	14,575	57.8	1,872,280	226,500	1,539,130	20.7	46,900	281,150	3.1	44,830	524,648
Oklahoma	2,304,200	1,171,295	1,983,657	1,870,145	50,805	42.3	810,380	398,184	409,009	10.7	35,871	339,737	5.2		371,743
Oregon	1,526,724	867,977	1,524,596	1,458,079	30,424	29.4	514,053	66,635	439,409	8.6	518	226,716	4.2	1,492	171,428
Pennsylvania	4,854,988	2,397,703	3,541,570	3,276,755	110,906	55.4	2,530,867	1,480,091	935,512	24.3	33,889	719,302	5.7	64,253	631,983
Rhode Island	579,625	285,760	519,889	518,991		7.4	141,760		141,760	1.5				60,634	144,000
South Carolina	1,364,791	488,000	1,061,039	1,059,079		33.8	347,035	241,028	106,007	12.7	64,684	71,628	3.6		310,365
South Dakota	1,502,870	761,911	1,042,346	1,041,308	808	35.8	190,966	123,944	67,022	7.8	115,858	125,648	7.9	221,760	568,433
Tennessee	2,123,155	1,121,790	1,697,413	1,642,201	37,444	24.0	759,732	469,994	289,738	7.3		184,393	1.9	10,960	610,214
Texas	6,642,663	1,795,000	5,010,219	4,862,342	37,599	114.1	2,032,785	1,484,599	363,895	31.5	18,745	450,359	10.7	277,177	943,147
Utah	778,826	533,173	778,597	649,146	65,900	20.2	332,584	129,130	187,706	4.5		204,500	7.4	550	75,067
Vermont	500,509	240,611	438,659	399,070		11.9	217,197	97,248	105,285	4.0		107,326	2.7	4,191	28,000
Virginia	2,008,458	941,347	1,379,573	1,256,944	92,998	26.7	1,081,522	571,646	300,947	8.2	67,775	306,492	6.8	112,093	240,910
Washington	1,977,260	776,603	2,073,550	1,913,253	139,163	36.5	494,715	56,928	437,787	9.9	3,957	171,774	2.2	3,121	27,879
West Virginia	1,342,270	570,085	1,017,695	968,033	13,293	16.7	359,679	344,863	14,816	4.7	29,374	72,008	2.7		469,968
Wisconsin	2,596,143	1,348,513	2,491,867	2,407,243	15,575	52.3	491,512	113,026	378,486	8.7		848,723	13.5	75,875	105,729
Wyoming	1,125,332	29,416	988,667	982,691	2,784	22.5	155,723	141,009	14,132	3.0				1,632	12,500
District of Columbia	946,445	243,460	922,671	696,281	226,390	6.5	250,164	250,164		.2					17,070
Hawaii															
TOTALS	115,822,245	48,705,383	93,899,442	88,056,420	2,264,540	1,742.6	43,846,974	22,992,477	18,219,624	510.2	2,395,459	10,037,133	217.4	2,377,889	18,184,086

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF APRIL 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 1,074,572	$ 1,073,654		81.6	$ 1,487,169	$ 908,870	$ 578,299	99.1		$ 238,167	20.9	$ 49,929	$ 248,495
Arizona	525,423	998,032	642,741	516,393	$ 101,099	52.6	687,377	9,030	603,790	57.2		58,169	8.7		234,974
Arkansas	1,449,634	857,024	1,223,026	1,217,347		149.0	458,917	156,240	301,561	59.5		296,237	32.4	76,047	259,226
California	3,480,440	1,999,203	3,590,636	2,984,134		164.3	1,493,714	494,605	868,356	45.0		492,620	24.1	1,700	638,227
Colorado	1,718,632	871,502	1,940,267	1,505,435	97,447	196.0	1,029,409	110,000	610,298	127.5	$ 3,197	75,032	5.0		88,726
Connecticut	659,120	420,868	160,282	160,282		3.1	740,403	498,838	235,769	16.4					185,099
Delaware	431,113	230,849	314,981	213,550	90,382	29.4	362,480	262,563	99,683	30.3		39,000	11.7		1,783
Florida	1,302,816	1,043,543	1,511,453	1,283,605	217,222	83.4	397,137		397,137	23.0		336,849	16.6	19,150	92,334
Georgia	2,320,973	1,273,373	1,367,881	1,364,873		106.4	896,693	770,461	126,232	54.9		306,570	32.2	185,638	845,571
Idaho	1,121,562	824,450	1,328,724	1,101,360	56,671	156.1	489,003		483,712	54.1		95,000	13.6	20,202	183,067
Illinois	5,652,228	3,345,525	2,231,124	2,198,495		134.1	6,020,232	3,443,885	2,576,347	314.6	9,848	769,178	36.7		
Indiana	731,872	135,970	393,706	338,288		44.2	325,333	310,433	14,900	43.4		113,139	12.3	33,152	7,931
Iowa	2,413,358	1,590,000	2,148,139	1,930,731	164,500	320.6	1,708,567	481,860	1,101,475	290.5		314,400	82.0	707	9,625
Kansas	2,528,401	1,330,595	2,198,510	2,113,655	74,572	213.0	1,237,748	381,253	906,495	89.0	27,493	349,528	6.5		
Kentucky	[illegible]	[illegible]	[illegible]	1,715,113	41,263	214.0	1,147,628	107,292	1,024,165	135.4		270,981	40.6	[illegible]	
Louisiana	[illegible]	[illegible]	967,509	963,328		47.9	542,816	308,877	233,939	20.6	127,387	575,867	30.1	27,287	29,147
Maine	342,479	427,347	1,024,290	842,479	146,816	86.7	275,022		256,302	20.9		13,278	.7		5,500
Maryland	841,132	1,067,934	735,179	692,648		52.1	564,266	172,531	391,735	28.6	20,419	211,449	5.7	5,535	464,750
Massachusetts	488,185	870,000	477,470	469,741		15.2						115,370	5.5	18,443	754,630
Michigan	3,184,057	1,613,142	2,899,613	2,822,085	16,400	205.5	1,409,527	341,727	1,052,900	59.4		502,675	34.7	20,245	41,167
Minnesota	2,376,415	1,361,813	2,384,797	2,189,842	143,394	266.7	1,207,137	155,444	919,593	117.4		228,132	14.7	31,129	70,695
Mississippi	1,744,669	354,023	961,631	961,631		101.6	717,351	717,351		58.4	22,312	101,740	24.0	43,374	252,283
Missouri	2,923,273	2,403,863	2,967,393	2,687,722	193,380	634.0	1,370,118	235,551	1,095,313	217.8		772,549	165.8		362,621
Montana	1,859,937	940,434	1,874,716	1,754,032	116,145	237.7	644,011		644,011	62.2		91,140	8.6	105,905	91,138
Nebraska	1,957,240	991,091	2,110,304	1,962,560	147,789	402.5	726,186		726,186	82.8		36,964	3.6	4,680	80,151
Nevada	1,136,479	862,000	[illegible]	1,113,354	151,347	143.5	469,768		469,768	61.3				23,126	230,385
New Hampshire	477,335	242,365	426,497	408,961	77,387	24.8	114,607	29,000	82,530	5.9		82,388	3.8	45,425	
New Jersey	55,994	460,000	55,628	55,099		.5						111,953	1.7		348,037
New Mexico	[illegible]	[illegible]	[illegible]	[illegible]	87,479	231.8	537,758	36,931	500,337	60.0		49,388	7.4		97,721
New York	[illegible]	[illegible]	[illegible]	[illegible]	28,069	84.3	4,374,470	515,500	[illegible]	247.4		524,500	44.8	54,942	213,362
North Carolina	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	260.1	1,441,273	[illegible]	1,217,466	155.4		60,000	12.6	26,560	154,377
North Dakota	[illegible]	734,741	899,550	893,931		275.4	409,371	321,903	88,068	106.8	169,959	196,749	119.9	60,319	[illegible]
Ohio	[illegible]	[illegible]	[illegible]	[illegible]	14,300	299.4	1,264,130	73,810	1,176,520	39.5		360,400	14.1	[illegible]	[illegible]
Oklahoma	[illegible]	[illegible]	[illegible]	1,564,014		256.1	1,271,601	411,491	[illegible]	59.9		321,215	21.7	3,694	154,241
Oregon	[illegible]	777,036	1,698,447	1,507,131	29,332	113.2	822,180	[illegible]	[illegible]	55.8		38,062	[illegible]	67	[illegible]
Pennsylvania	[illegible]	[illegible]	6,441,090	6,215,717	81,624	[illegible]	3,623,019	1,178,605	2,306,191	213.6		114,181	[illegible]		[illegible]
Rhode Island	[illegible]	[illegible]	444,748	[illegible]		33.2	212,563		212,563	6.7					[illegible]
South Carolina	[illegible]	[illegible]	[illegible]	[illegible]		115.5	1,094,312	[illegible]	[illegible]	132.2	49,827	[illegible]	49.9	[illegible]	[illegible]
South Dakota	[illegible]	[illegible]	[illegible]	1,174,187	[illegible]	346.5	371,342	310,094	[illegible]	[illegible]	16,937	[illegible]	88.4	[illegible]	[illegible]
Tennessee	[illegible]	[illegible]	[illegible]	[illegible]		112.6	[illegible]	672,589	423,716	[illegible]	4,603	[illegible]	21.9	77,061	[illegible]
Texas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	773.3	[illegible]	[illegible]	[illegible]	168.3		[illegible]	[illegible]	[illegible]	[illegible]
Utah	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	162.7	455,943	94,022	[illegible]	75.0		[illegible]	[illegible]		[illegible]
Vermont	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37.2	193,930		191,498	13.8		[illegible]	[illegible]	[illegible]	[illegible]
Virginia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	111.1	[illegible]	101,973	[illegible]	[illegible]	16,517	147,140	21.4	[illegible]	[illegible]
Washington	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					[illegible]
West Virginia	[illegible]	[illegible]	[illegible]	[illegible]		41.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Wisconsin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46.1		[illegible]	[illegible]	[illegible]	[illegible]
Wyoming	[illegible]	[illegible]	[illegible]	[illegible]	74,583	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52,747	[illegible]	[illegible]		[illegible]
District of Columbia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.7	[illegible]		[illegible]	3.8		[illegible]	.4		[illegible]
Hawaii	[illegible]	[illegible]	[illegible]	[illegible]		4.4									[illegible]
Totals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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SEPARATE REPRINT FROM THE YEARBOOK

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TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF APRIL 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ [illegible]	$ [illegible]	$ [illegible]	$ 5,739,877	$ 75,355	433.0	$ 4,896,992	$ [illegible]	$ 2,000,675	279.9	$ 209,224	$ [illegible]	38.3	$ 75,057	$ 1,540,677
Arizona	5,211,960	2,641,935	5,840,400	4,823,006	371,153	380.7	[illegible]	189,792	[illegible]	133.4	129,322	218,711	9.9	69,840	466,491
Arkansas	[illegible]	3,428,049	[illegible]	[illegible]	168,656	345.9	[illegible]	1,045,748	1,327,130	145.7	[illegible]	1,063,405	66.3	[illegible]	368,368
California	[illegible]	7,932,006	16,947,046	13,410,639	14,200	489.7	8,075,931	[illegible]	4,177,283	198.5		2,128,654	55.5	16,806	1,016,069
Colorado	[illegible]	[illegible]	[illegible]	6,584,691	738,998	424.2	3,159,362	232,944	2,499,863	226.3	3,137	80,004	5.0	53,698	100,141
Connecticut	2,865,740	1,444,868	1,767,458	1,753,636	6,949	27.8	2,331,871	1,107,773	955,734	41.0		143,909	1.7	4,331	348,276
Delaware	1,819,038	923,395	1,821,701	1,547,303	312,926	78.7	665,530	271,296	381,145	37.1		83,092	13.5	438	146,232
Florida	[illegible]	2,661,343	6,346,938	4,923,984	314,521	221.4	1,372,866	194,391	1,127,318	57.7	2,898	637,186	21.8	[illegible]	[illegible]
Georgia	[illegible]	5,113,491	6,539,629	6,424,848		420.2	4,863,139	3,130,145	1,723,993	224.7	64,971	864,125	61.7	[illegible]	[illegible]
Idaho	[illegible]	2,277,486	4,630,487	4,136,445	166,607	361.5	1,280,575	245,868	[illegible]	101.8		[illegible]	13.7	[illegible]	[illegible]
Illinois	[illegible]	8,921,401	10,229,969	[illegible]	19,269	[illegible]	[illegible]	7,464,801	4,906,765	391.9	70,011	[illegible]	[illegible]	[illegible]	[illegible]
Indiana	[illegible]	[illegible]	6,649,913	6,454,073		210.9	4,722,373	3,262,341	1,422,353	132.4	216,332	[illegible]	146.5	[illegible]	[illegible]
Iowa	[illegible]	[illegible]	[illegible]	[illegible]	226,005	663.2	5,506,522	[illegible]	3,575,435	445.7	1,000	[illegible]	[illegible]	[illegible]	[illegible]
Kansas	[illegible]	5,117,675	[illegible]	[illegible]	375,125	645.7	5,160,372	[illegible]	[illegible]	271.7	[illegible]	[illegible]	[illegible]	[illegible]	
Kentucky	7,517,369	[illegible]	6,862,560	6,416,050	74,334	489.5	[illegible]	1,017,175	[illegible]	216.2	30,000	1,180,657	[illegible]	54,134	[illegible]
Louisiana	5,828,591	2,963,932	3,558,878	3,493,153	53,647	142.3	3,933,493	2,062,294	1,330,716	52.9	245,347	1,013,068	49.2	27,287	566,501
Maine	3,369,917	1,711,536	3,255,453	2,937,470	146,316	146.8	1,176,562	290,947	806,895	34.8	88,566	322,731	10.1	2,934	375,144
Maryland	3,564,527	1,810,058	1,933,571	1,868,277	16,517	71.5	2,477,909	1,067,832	596,497	50.6	171,247	211,449	6.2	457,112	935,595
Massachusetts	6,597,100	3,350,474	4,026,820	3,584,571		66.1	4,039,943	2,929,059	1,034,037	18.2		348,027	13.2	83,470	1,968,361
Michigan	17,736,227	[illegible]	11,067,537	10,645,937	120,800	469.7	6,592,002	2,005,077	4,519,325	208.4	14,950	1,321,475	76.9	70,213	491,018
Minnesota	10,656,569	5,425,551	11,250,473	9,443,465	1,579,594	1,266.1	2,535,500	506,613	1,856,186	233.3	516,059	786,890	90.6	190,432	1,202,881
Mississippi	6,978,675	3,540,227	6,249,855	4,032,673	215,294	364.8	4,426,546	2,484,457	1,159,727	230.0	[illegible]	1,174,971	97.5	99,475	990,234
Missouri	12,180,306	6,173,740	10,508,984	9,631,116	193,380	874.1	5,607,236	2,330,020	2,965,005	314.8	23,343	[illegible]	175.6	195,827	1,944,153
Montana	7,439,748	3,703,734	8,331,712	[illegible]	1,070,983	753.6	2,309,888	38,846	2,177,532	202.3	28,667	230,935	30.0	164,325	284,285
Nebraska	7,823,961	3,964,364	9,337,068	7,767,835	368,219	806.3	3,575,309	25,924	3,147,550	193.1	3,918	183,574	13.6	31,285	260,022
Nevada	4,545,317	2,302,356	4,629,513	4,256,393	283,199	430.1	1,744,279	179,532	1,503,437	212.8	17,734	19,855	2.6	[illegible]	495,866
New Hampshire	1,909,839	969,462	1,867,165	1,684,126	127,239	51.6	770,771	180,288	565,513	21.4		101,061	3.8	45,425	175,644
New Jersey	6,346,039	[illegible]	4,414,852	4,263,607		53.5	2,916,897	2,046,600	566,347	23.7		760,038	5.5	35,531	1,834,494
New Mexico	5,730,935	2,941,700	6,177,461	5,391,546	641,986	584.4	1,814,182	317,448	1,425,840	143.4	3,119	222,561	22.5	80,822	651,313
New York	22,330,101	11,327,921	21,021,323	18,031,652	496,419	354.6	17,512,994	3,975,927	9,104,220	419.1		993,800	50.6	322,522	733,483
North Carolina	9,522,293	4,840,941	9,172,462	7,723,291	561,034	913.1	3,504,633	1,214,178	1,977,892	331.2	250,323	738,314	46.9	334,501	1,513,701
North Dakota	5,804,443	2,938,967	5,039,524	4,528,561	57,900	1,342.2	1,204,342	573,957	525,171	325.8	445,392	893,432	370.8	251,538	1,462,464
Ohio	[illegible]	7,865,012	15,915,582	14,763,269	28,875	548.4	6,468,150	393,910	5,638,240	186.6	148,198	658,270	19.4	179,214	1,539,627
Oklahoma	9,216,798	4,685,180	8,269,896	7,844,331	117,410	598.7	4,393,467	1,322,874	2,690,573	160.6	45,900	978,576	39.9	3,694	838,621
Oregon	6,106,896	3,097,814	6,671,594	5,936,759	204,379	328.5	2,495,399	96,951	2,266,529	121.3	70,318	286,778	11.1	2,869	340,128
Pennsylvania	18,891,004	9,590,788	15,893,086	14,988,262	362,237	723.4	11,543,363	3,752,217	7,368,368	333.0	36,015	889,565	12.7	114,509	970,618
Rhode Island	1,998,708	1,014,572	1,937,643	1,858,334		61.1	914,914	79,740	818,895	22.5				60,634	195,678
South Carolina	5,459,165	2,770,954	4,482,416	4,391,579	27,818	348.3	2,250,557	855,142	1,356,379	216.4	151,388	551,319	55.7	61,056	835,437
South Dakota	6,011,479	3,047,643	4,980,312	4,423,069	95,502	840.7	1,889,005	1,087,739	774,588	364.8	220,198	1,114,256	220.2	280,474	1,063,297
Tennessee	8,492,619	4,302,991	7,776,265	6,961,922	101,596	319.1	3,482,668	1,392,210	1,994,056	117.1	13,992	792,956	31.4	124,495	1,414,382
Texas	24,244,024	12,291,253	23,440,032	21,979,351	373,789	1,899.1	8,792,443	1,864,899	6,555,321	582.0	105,466	3,007,092	197.6	294,309	2,355,051
Utah	4,194,708	2,132,691	4,809,343	3,881,020	564,813	440.7	1,612,453	307,765	991,962	141.3		317,175	19.6	5,903	256,740
Vermont	1,867,573	948,007	1,906,133	1,739,032	45,033	97.0	765,099	107,918	606,062	33.3		254,383	9.4	20,623	42,530
Virginia	7,416,757	3,765,387	6,762,830	6,178,683	272,056	397.1	3,396,735	878,943	2,166,257	127.2	137,216	609,814	47.2	221,915	717,260
Washington	6,115,867	3,106,412	5,955,885	5,545,214	345,052	199.6	2,834,379	528,607	2,133,495	92.1	5,442	381,682	3.4	36,604	246,184
West Virginia	4,474,234	2,280,335	3,693,430	3,520,784	74,185	129.8	1,566,837	843,391	706,554	48.9	78,199	385,868	14.7	31,859	1,113,728
Wisconsin	9,724,881	4,941,837	9,107,185	8,671,982	72,394	430.2	3,249,384	875,321	2,046,573	126.5	182	2,174,991	49.7	177,396	647,879
Wyoming	4,501,327	2,287,712	4,672,219	4,068,220	414,703	679.1	1,442,620	377,337	1,038,535	180.6	50,747	730,793	174.5	5,023	103,680
District of Columbia	1,918,469	973,842	2,024,749	1,668,305	356,444	15.2	574,751	250,164	324,587	3.9		65,390	.4		227,420
Hawaii	1,871,062	949,778	597,809	451,692		18.5	1,763,640	1,412,579		26.0				6,791	949,778
TOTALS	394,000,000	200,000,000	359,989,925	320,522,487	12,311,911	22,393.5	187,674,697	63,807,071	107,487,097	8,803.9	4,129,583	36,492,884	2,642.8	5,540,859	43,708,108

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 4 ▽ JUNE 1935

DETERMINING DEPTH TO ROCK BY MEASURING EARTH RESISTIVITY

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 16, No. 4 June 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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SUBSURFACE EXPLORATION BY EARTH RESISTIVITY AND SEISMIC METHODS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by E. R. SHEPARD, Research Engineer

DURING the past 2 years the Bureau of Public Roads has experimented with two geophysical methods of subsurface exploration, with the expectation that they will prove of value in foundation exploration, in the location of gravel deposits and other surfacing material, and even as an aid to classifying excavation in highway construction.

One of these methods of test—the electrical resistivity method—has been used for some years with varying degrees of success by several State highway organizations in connection with grading operations, fills through swamps, and for determining the location and extent of gravel deposits and quarry material.

The other method, known as the "seismic method", although used extensively for locating salt domes and other oil-bearing structures and in certain types of mining operations, has not heretofore been applied to shallow determinations. However, tests by the bureau over a period of several months on known formations around Washington indicate that, for determining the presence and location of consolidated rock, this method is more reliable and accurate and in other ways superior to the resistivity method.

These and other scientific methods of subsurface exploration are not new to the geophysicist. For many years the magnetometer has been used in the location of mineral deposits. The Eötvös torsion balance, a gravimetric instrument, was introduced into this country from Germany about 1922, and through its use many salt domes rich in oil and sulphur were discovered in the Gulf Coast region.

More recently the seismic method of exploration has come into use and is now the most popular and widely used of all geophysical methods for deep exploration work. Various electrical methods of exploration are also in use; of these the resistivity method is finding much favor where relatively shallow determinations are involved.

UNDERGROUND CONDITIONS INDICATED BY ELECTRICAL RESISTIVITY

In using the resistivity method of exploration the most common procedure is to introduce an electric current of known strength into the earth through suitably placed electrodes and by means of intermediate electrodes to measure the average resistivity of a volume of earth comparable in dimensions to the electrode spacing. By progressively increasing the electrode spacing and repeating the measurements a curve is established which shows the relation of resistivity to depth.

Calculated values of resistivity are plotted as ordinates and corresponding values of electrode spacing as abscissas. An upward trend of the curve indicates increasing resistivity with depth and suggests the presence of rock, gravel, or some other high-resistance material, while a flat or descending curve is indicative of soil or clay. An abrupt change in curvature indicates a change in material at a depth approximately equal to the electrode spacing at which the change occurs.

Studies of this kind have been reported by the Bureau of Mines (*4*, *5*, *6*, *9*),[1] by Schappler and Farnham (*8*) of the Missouri State Highway Commission, by Kurtenacher (*2*, *3*) of the Wisconsin Highway Commission, by Wilcox (*12*) of the Minnesota Department of Highways, and by numerous other investigators. Schappler and Farnham were successful in preclassifying excavation materials on highway projects but had difficulty in interpreting bridge sounding data due to the fact that coarse sand and gravel overlying the bedrock possessed a resistivity not markedly different from that of the solid rock. Kurtenacher reported success in the determination of the thickness of stripping in quarries, the location of buried gravel deposits, and the determination of depths to solid bottom in marshes and swamps. Wilcox has confined his work largely to locating shallow deposits of sand and gravel for road surfacing.

The following quotation from the report of Schappler and Farnham shows that in 1931, without the aid of resistivity measurements, an error of nearly 13 percent was made in estimating the amount of solid-rock excavation on a number of highway jobs, while in 1932, on a like number of similar jobs where estimates were based on resistivity tests, the error was about 1 percent. This comparison suggests the possibility of greatly improving the accuracy of estimates of grading costs on highway projects through the use of this or other methods of preliminary exploration.

> Up to date final estimates have been filed on 25 projects completed in 1932, on which geologists had made reports and preclassified the excavation. The projects were matched as nearly as possible with projects completed in 1931. On the basis of this comparison it was found that the present scheme of preclassifying predicted that 8.32 percent of all the excavation quantities would be solid rock, whereas final estimates consider 9.36 percent of the excavation as solid rock—an overrun of 1.04 percent. In 1931 preliminary classification predicted 21.79 percent solid rock whereas final classification gave 8.87 percent or an underrun of 12.92 percent. Limiting this comparison to 15 projects typical of the more difficult area—the Ozark region—in 1932 final classification overran the predictions 3.13 percent, while in 1931 there occurred an underrun of 24.44 percent. Although this analysis is far from complete, it does express the general results of this method of preclassifying excavation materials. Predictions are more nearly accurate than formerly and instead of the tendency to greatly overclassify the solid rock the present trend is toward slightly underclassifying.

PRINCIPLES INVOLVED IN RESISTIVITY MEASUREMENTS DISCUSSED

The principle involved in making earth-resistivity measurements is illustrated in figure 1. An electric current, *I*, is caused to flow through the earth between two electrodes, C_1 and C_2. Measurement is then made of the potential drop, *E*, between two intermediate electrodes, P_1 and P_2, placed in line with C_1 and C_2 and dividing the distance C_1C_2 into 3 equal parts, *A*, termed the electrode spacing.

In 1915 Wenner (*11*) showed that with this 4-electrode arrangement the specific resistivity of a homogeneous medium is given by the equation,

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[1] Italic numbers in parentheses refer to [illegible]

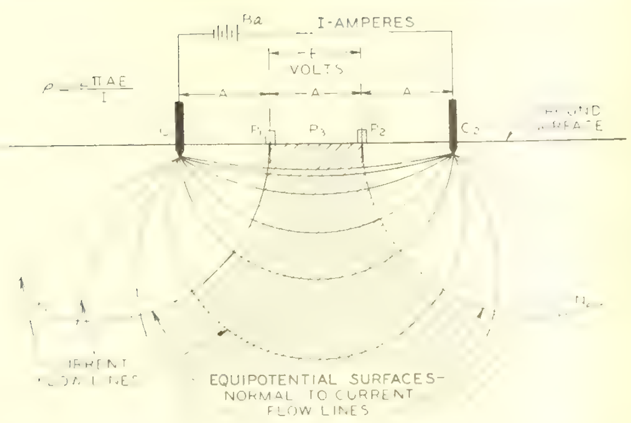


Figure 1.—Diagram for Use in Discussing Theory of Earth Resistivity Measurements.

$$\rho = \frac{2\pi AE}{I} \qquad (1)$$

where A is expressed in centimeters. The specific resistivity, ρ, is expressed in ohm-centimeters and denotes the resistance in ohms between parallel faces of a centimeter cube of the material. Where A is measured in feet we may write,

$$\rho = 191A\frac{E}{I} \qquad (2)$$

If the medium is not homogeneous the indicated resistivity, ρ, represents an average specific resistivity of the material bounded by the equipotential surfaces P_1N_1 and P_2N_2 but its value is determined largely by the properties of the material near the surface and only slightly by the material at a relatively great depth. The experience of numerous investigators is rather consistent in showing that for practical depth determinations the materials within a depth equal to the electrode spacing, A, largely determine the value of ρ, and that materials at a depth greater than A have a negligible influence on the value of ρ.

Let us assume in figure 2 that a homogeneous soil of resistivity ρ_1 exists to a depth H and that below the horizon H a material of greater resistivity ρ_2 exists. If, under this condition, earth resistivity measurements are made with different values of electrode spacing, A, as indicated in figure 1, and a curve is plotted showing the relation of ρ to A, as in figure 2, we find that for values of A less than H the curve *ab* is approximately flat, but when A begins to exceed H the influence of the deeper material begins to affect the value ρ and the curve assumes an upward trend as at *b*. Rather abrupt changes of this kind are often obtained in practice and afford a means of roughly determining the depth to a change in material. This is a simple empirical rule, but one for which there is no theoretical basis.

Tagg (*10*) and others have shown that from theoretical considerations the curve in figure 2 should assume some such form as a′bcd with no sharp breaks or inflections. In practice, however, and especially on shallow work, rather sharp inflections are frequently obtained where materials of different resistivities are concerned, and these inflections afford a simple and satisfactory means of ascertaining the approximate depth where the change in material occurs.

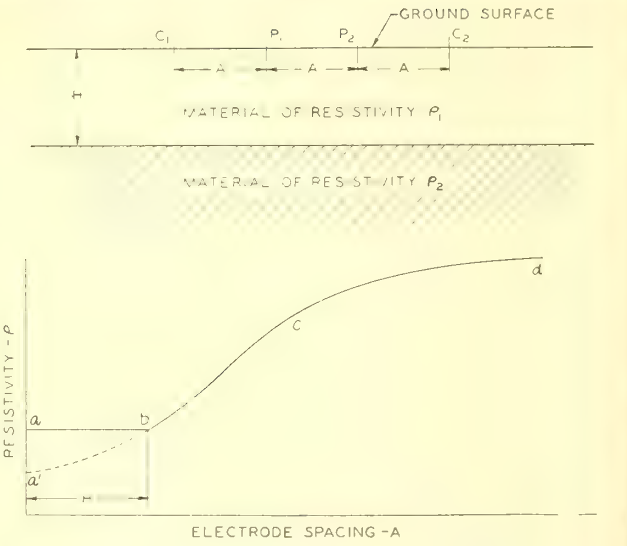


Figure 2.—Typical Resistivity Curve.

Perhaps a more common occurrence is a U-shaped curve in which the electrode spacing at the low point is taken as the depth to a change in material. The descending branch of the curve is characteristic of many soils in which a decreasing resistivity occurs with increase in depth. Under such conditions an underlying strata of rock or gravel is indicated quite accurately by the low point of the curve.

VARIOUS TYPES OF INSTRUMENTS USED FOR RESISTIVITY MEASUREMENTS

Three types of instruments are being used for earth resistivity measurements, and each has its advantages and disadvantages. As the men who are often called upon to do this class of work are more likely to have had technical training in geology or civil engineering than in electrical science, it will be appropriate to discuss the several methods and instruments currently employed, in order that the most suitable arrangement of apparatus may be selected to meet any particular set of requirements. Before discussing the instruments themselves, it will be well to consider certain inherent difficulties that are encountered in earth-resistivity measurements.

The measurements indicated in figure 1 are not as simple as they are here made to appear. Several sources of stray currents and potentials are likely to exist and must either be eliminated or compensated for if an accurate determination of E, the potential drop in the earth between P_1 and P_2, resulting from the current I, is to be obtained. These sources are, (1) self potentials originating in local mineral deposits; (2) natural earth currents of large scope but not often of troublesome magnitude; (3) local stray currents originating from street-railway systems, grounded power circuits, or mine railways. These are usually variable in character and are especially troublesome near large city-railway systems or interurban electric lines. Other sources are, (4) galvanic and polarization potentials between electrodes P_1 and P_2; (5) galvanic potentials originating from cinders, coke, or filled ground containing bits of metal or other foreign materials.

In addition to overcoming these stray-current effects, it is necessary to avoid taking any current from the electrodes P_1 and P_2 while making a measurement of E, as a flow of current through these electrodes will distort or upset the true potential difference between them esulting from the flow of the current I. This latter ondition is usually met by employing a potentiometer, hich draws no current from the potential source being easured, or a voltmeter or galvanometer of extremely igh resistance that draws a negligible current from ie electrodes. To overcome the stray-current effects is customary to use alternating current or its equivant—a periodically reversed current—as stray-current fects are essentially unidirectional and are not reorded on the instruments that measure the alternating periodic current.

In his original paper, Wenner proposed the use of ternating current supplied from a transformer. A viration galvanometer was so placed in the circuit as to etect a balance between the voltage at the electrodes and P_2 and that on a measured length of slide wire ipplied from the secondary side of the transformer. balance was indicated when no current flowed through ie galvanometer. Such apparatus is obviously not iited to rapid field measurements.

The first practical application of the four-electrode ethod of measuring earth resistivity was made by IcCollum (*7*) of the Bureau of Standards in a study stray-current electrolysis on underground pipes and ble systems. The McCollum earth-current meter nbodies a dry battery, a milliameter, a double comutator, and a voltmeter having a resistance of 1,000,00 ohms per volt. Current, after passing from the attery through the milliameter, is commutated at a equency of about 30 cycles per second and then conicted to the two current electrodes. This periodic irrent establishes a potential difference of the same equency between two potential electrodes. Leads om the potential electrodes are carried to a second mmutator mounted on the same shaft with the curnt commutator and in phase with it. The effect of is second commutator is to rectify the periodic potenal, after which it is measured on the direct-current, igh-resistance voltmeter. It will readily be seen that ıy direct stray current which may exist in the earth iould not affect the direct-current voltmeter because having first passed through the potential commutator.

A set of four electrodes mounted on a frame as a unit, ith a 3-inch interval, is commonly used with the earthirrent meter in the study of stray-current electrolysis. lthough this instrument is extensively used on elecolysis work, it apparently has not found application in ophysical exploration. There is no reason, however, hy it should not be used for this purpose and it might rove particularly suited to shallow determinations.

Gish (*1*) of the Department of Terrestrial Magnetism id Atmospheric Electricity of the Carnegie Institute odified the McCollum earth-current meter and measred the resistivity of large volumes of earth. His strument embodied a larger and more accurate comutator than that employed by McCollum and he subituted a potentiometer for the high-resistance volteter. He also introduced a condenser into the tential circuit to block the passage of galvanic and ray direct currents from the ground to the potentiomer, and reduced leakage between the current and the tential circuits by the addition of a guard ring. This pe of apparatus has been used quite extensively for ophysical explorations during recent years.

Another instrument, known commercially as the negger" (*4*), was designed primarily to measure the sistance of driven and buried grounds for power stations and electric circuits, but is also used successfully under certain favorable conditions for subsurface exploration. It embodies a hand-driven, direct-current generator, a double commutator on the same shaft with the generator, and a single indicating instrument known as an "ohmmeter." By a special arrangement of the coils and magnetic circuit this meter is made to register the ratio $\frac{E}{I}$ and thus indicates ohms directly. The fact that this instrument must, of necessity, draw current from the potential electrodes is distinctly a disadvantage. The error is not serious in determinations involving moderate depths if the contact resistance of the potential electrodes is kept reasonably low. Sometimes it is necessary to use water and rather long potential stakes. If accurate values of resistivity are desired, it is necessary to measure the resistance of each potential stake to ground and to compute certain correction factors based on these measured resistances.

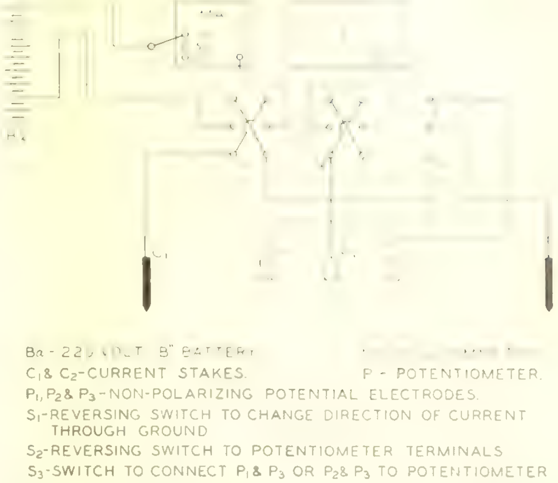

Ba - 22½ VOLT "B" BATTERY
C₁ & C₂-CURRENT STAKES.
P - POTENTIOMETER.
P₁, P₂ & P₃-NON-POLARIZING POTENTIAL ELECTRODES.
S₁-REVERSING SWITCH TO CHANGE DIRECTION OF CURRENT THROUGH GROUND
S₂-REVERSING SWITCH TO POTENTIOMETER TERMINALS
S₃-SWITCH TO CONNECT P₁ & P₃ OR P₂ & P₃ TO POTENTIOMETER

FIGURE 3.—CIRCUIT DIAGRAM FOR EARTH RESISTIVITY MEASUREMENTS.

Eve, Keys, and Lee (*4*) of the Bureau of Mines have shown that comparative values of resistivity as obtained with the megger are often subject to the same interpretations as are similar data obtained by more precise methods. An improved megger, designed especially for geophysical work, and embodying a potentiometer, is said to be available now.

METHOD DEVISED FOR MAKING RESISTIVITY DETERMINATIONS RAPIDLY

Among the several methods of test used by the Bureau of Mines (*9*) is that embodying a simple direct-current circuit with a reversing switch instead of a commutator. Nonpolarizable potential electrodes are also substituted for the conventional iron stakes. Lee (*5*) also introduced a center potential electrode with which it is possible to determine underground slopes by making independent measurements on either side of the center. This type of apparatus is the one adopted and used by the Bureau of Public Roads.

Its essential features are shown in figures 3 and 4. Special potential electrodes are used to minimize polarization and galvanic potentials. They consist of a copper electrode submerged in a concentrated solution of copper sulphate in an unglazed porous cup. Cups 10 centimeters high and 5.2 centimeters in diameter

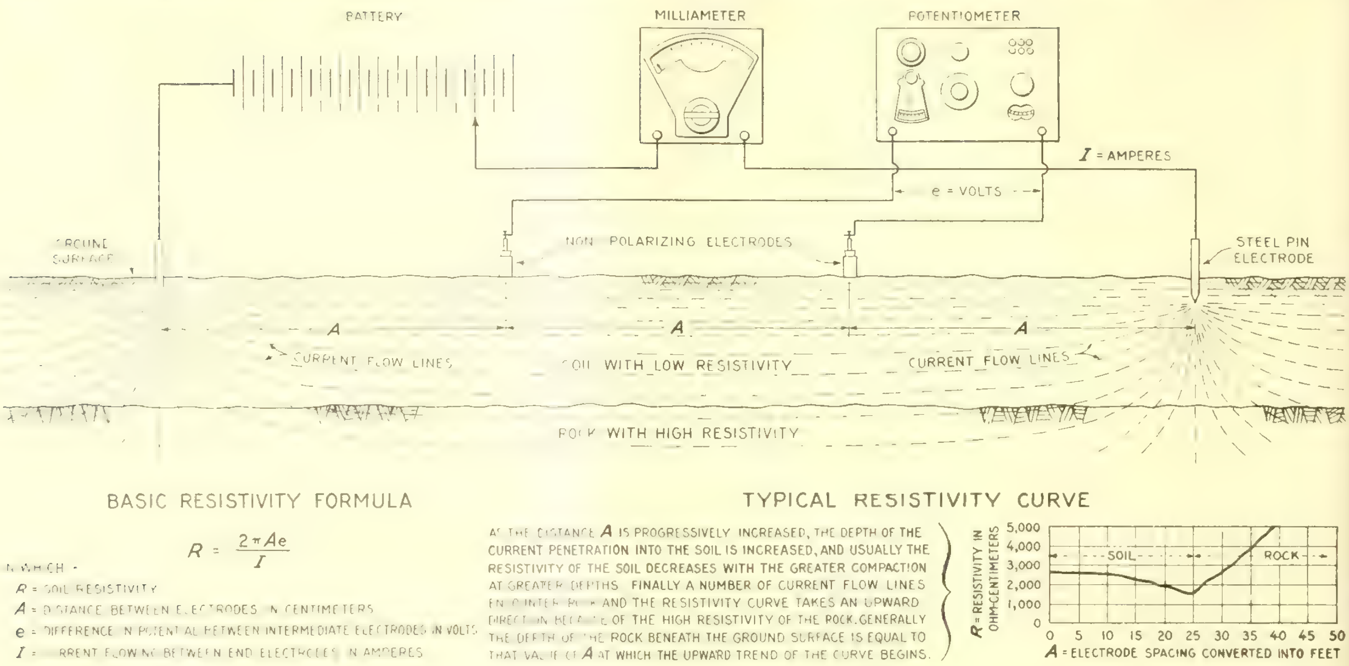

BATTERY
MILLIAMETER
POTENTIOMETER
I = AMPERES
e = VOLTS
GROUND SURFACE
NON POLARIZING ELECTRODES
STEEL PIN ELECTRODE
A
A
A
CURRENT FLOW LINES
SOIL WITH LOW RESISTIVITY
CURRENT FLOW LINES
ROCK WITH HIGH RESISTIVITY
BASIC RESISTIVITY FORMULA
R = 2πAe / I
IN WHICH -
R = SOIL RESISTIVITY
A = DISTANCE BETWEEN ELECTRODES IN CENTIMETERS
e = DIFFERENCE IN POTENTIAL BETWEEN INTERMEDIATE ELECTRODES IN VOLTS
I = CURRENT FLOWING BETWEEN END ELECTRODES IN AMPERES
TYPICAL RESISTIVITY CURVE
AS THE DISTANCE A IS PROGRESSIVELY INCREASED, THE DEPTH OF THE CURRENT PENETRATION INTO THE SOIL IS INCREASED, AND USUALLY THE RESISTIVITY OF THE SOIL DECREASES WITH THE GREATER COMPACTION AT GREATER DEPTHS. FINALLY A NUMBER OF CURRENT FLOW LINES ENCOUNTER ROCK AND THE RESISTIVITY CURVE TAKES AN UPWARD DIRECTION BECAUSE OF THE HIGH RESISTIVITY OF THE ROCK. GENERALLY THE DEPTH OF THE ROCK BENEATH THE GROUND SURFACE IS EQUAL TO THAT VALUE OF A AT WHICH THE UPWARD TREND OF THE CURVE BEGINS.
R = RESISTIVITY IN OHM-CENTIMETERS
5,000
4,000
3,000
2,000
1,000
0
SOIL
ROCK
0 5 10 15 20 25 30 35 40 45 50
A = ELECTRODE SPACING CONVERTED INTO FEET

Figure 4.—Arrangement of Apparatus for Measuring Electrical Resistivity.

are used. When not in use they are kept in an earthen jar containing a solution of copper sulphate. They should not be brought in contact with metals. Iron stakes 1¼ inches in diameter and about 2 feet long are used for current electrodes.

A milliammeter having ranges of 10, 50, and 250 milliamperes and a potentiometer are mounted on a 12- by 21-inch oak board, together with the switching arrangements shown in figure 4. The milliammeter is elevated to the same level as the face of the potentiometer and the switches are installed on the vertical front of its support. Leads of no. 18 lamp cord are used. These are wound on 4 brass spools which are mounted on a 9- by 12-inch board. This unit is provided with a flat bayonet attachment by which it is mounted on the back of the instrument unit when in operation. Another unit containing batteries, and two folding camp stools completes the equipment. The battery box provides for 9 "B" batteries of 22½ volts each, with additional space for tapelines, connecting leads, and porous cups. Two leads connect the battery to the instrument, and a dial switch on the top of the battery box enables any number of the units to be connected in circuit. Plugs and jacks are used to connect the lead terminals and the battery to the instrument, and small battery clips are used to connect the leads to the ground electrodes.

To eliminate the effect of any stray ground current of a constant and unvarying character, readings are taken with the test current flowing through the ground, first in one direction and then in the other. The reversing switch, S_1, is used to reverse current direction. Potential drop readings are taken between P_3 and P_1 and between P_3 and P_2 for both directions of current flow. Four values of current and four values of potential drop are thus obtained for each electrode setting, and from these data four values of R are computed with the formula $R=\frac{E}{I}$. Resistivities are computed by substituting in equation 2 after adding the two values of R obtained on either side of the center. If the two values of R are averaged, then a constant of 382 instead of 191 must be used in equation 2. By repeating these measurements for a series of electrode spacings it is possible to construct two resistivity curves as shown in B, C, D, and E, figure 5, which apply along the line of test on either side of the center electrode.

A fairly rapid technic has been developed which enables 2 engineers and 2 helpers to make from 10 to 20 shallow tests per day. By shallow tests is meant those involving such depths as are encountered in highway grading through rough country and requiring from 6 to 20 measurements at each test location. An electrode spacing of 3 feet, or multiples thereof, has been adopted as standard and both current and potential stake locations are marked on the plain side of two 100-foot linen tape lines to conform to a 3-foot interval Potential electrode locations are marked by consecutive numbers in red while every third position is marked consecutively in black to indicate current stake positions. The end links of the two tapelines are brought together at the center point of the test and a surveyor's iron pin stuck through them and into the ground The tapelines are then run out to their full length in either direction and pinned to the ground in a taut position. With 1 man to read the instruments, 1 to record the data and compute the resistivities with slide rule, and 2 helpers to move the electrodes progressively from point to point, it is possible to run a 60-foot depth test in from 30 to 40 minutes.

EQUIPMENT LOW IN COST AND GIVES ACCURATE RESULTS

The curves are plotted before moving and any irregularities are checked on both paper and ground before leaving the set-up. Sometimes it is desirable to obtain additional points on the curves in order to definitely establish the points of inflection. By this procedure it is usually possible to obtain fairly smooth and consistent curves. No sharp inflections have been found except at shallow depths. The jagged and pointed curves reported by some investigators for depths o

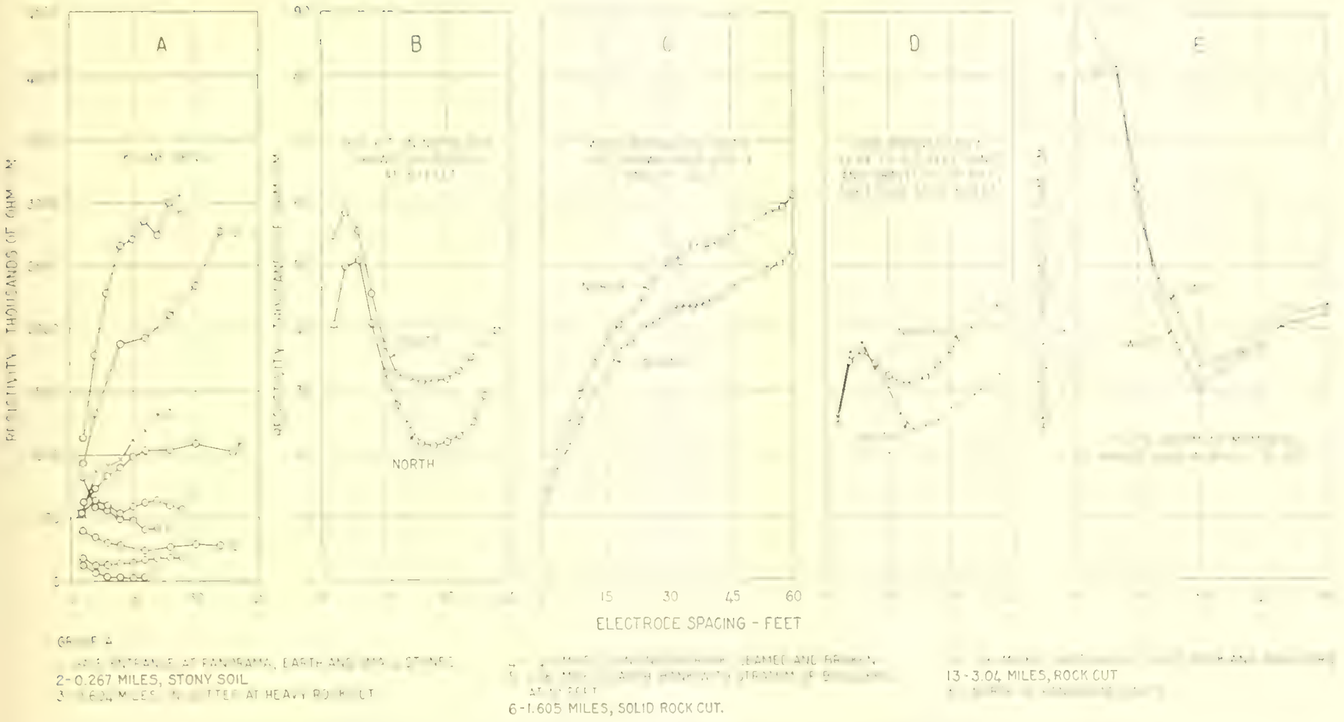


Figure 5.—Results of Earth Resistivity Measurements.

several hundred feet cannot be reconciled with either theory or careful practice.

Some trouble from stray current from electric railways has been encountered in and near Washington when attempting depth measurements in excess of about 50 feet. This difficulty can usually be met by using sufficiently large test currents to mask the effects of the variations in the stray currents and by taking the average of several readings for each electrode interval. It seems probable, however, that active stray currents will preclude the use of this method of measurement for depths in excess of 100 to 200 feet. To compensate for this disadvantage there are a number of advantages that make this so-called "porous-cup" method of test preferable to all others. These include low cost of equipment and high accuracy under a wide range of depths and resistivities.

When working in soils of unusually high resistivity, especially during dry periods, it is sometimes difficult to get enough current through the potential electrodes to operate the megger and other commutator devices. Even though a potentiometer is used in the potential circuit, the small amount of current required to charge the leads is sometimes sufficient to upset the normal potential relations. The only effect of such a condition when using the porous-cup method is a reduced sensitivity of the potentiometer galvanometer caused by the high resistance of the circuit. However, as no current is actually drawn from the potential electrodes, a satisfactory balance is always obtained. The porous cups are placed directly on the ground surface. Leaves, grass, and trash are usually removed. Unless the soil is dust-dry, no difficulty is encountered in obtaining satisfactory readings. With other types of apparatus it is often necessary to water the electrodes or drive them to a considerable depth. One case is reported where potential stakes 12 feet in length were used in connection with megger tests.

The paper and slide-rule work involved in the porous-cup method is somewhat greater than with other methods of test because of the necessity of making four sets of observations for each electrode interval. With the Gish-Rooney apparatus only two sets of readings are necessary, while with the megger no division operations are required as the instruments indicate ohms directly. It is necessary, however, to multiply the megger readings by a constant and by the electrode spacing to obtain actual resistivity values.

As to weight and portability, the megger and the earth-current meter are about on a par, and both are considerably lighter than either the Gish-Rooney or the porous-cup apparatus. None of the instruments require very accurate leveling. The Gish-Rooney apparatus is scientifically more accurate than any of the others and will perhaps yield satisfactory data for a greater variety of conditions than the others. For the relatively shallow depths encountered in highway construction, as well as for deeper determinations where stray-current disturbances are absent, the porous-cup apparatus appears to be entirely satisfactory and is favored because of its low cost and its simplicity of construction and operation.

FIELD TESTS MADE WITH RESISTIVITY APPARATUS

Resistivity measurements carried out by the Bureau of Public Roads have been confined largely to experimental studies of known formations for the purpose of developing suitable apparatus and methods of test and to determine the conditions under which this method of exploration may be of value in planning highway and bridge construction. Army engineers have made many borings in and about Washington in connection with the planning of bridges and other structures and these data afforded an excellent opportunity to check resistivity tests against the logs of these borings.

A period of several weeks was spent along the projected route of the Skyline Drive in the Shenandoah National Park, on both graded and ungraded sections. Preliminary measurements were made opposite cuts along graded sections prior to working along sections where grading was soon to begin. Part of the route on which measurements were made was examined after the grading had been completed and comparisons made between the field notes and the exposed cuts. Figure 5 shows a few of the many resistivity curves obtained. The curves in group A, figure 5, were all made along graded sections of the Skyline Drive, while curves B, C, D, and E were obtained near Washington. In group A only one of the two curves obtained at each location is shown.

Perhaps the most significant features brought out by these studies are the wide range in resistivities of both soil and rock encountered within a comparatively limited area, and the lack of uniformity and regularity in the upper layers of the earth's crust. Soil resistivities often vary enormously from hill to hill, and adjacent mountains may exhibit distinctly different characteristics with respect to soil and rock. Igneous intrusion, sedimentation, erosion, faulting, weathering, folding, and other geologic forces have contributed to make the earth's surface so erratic and irregular in its composition that no systematic continuity of materials is to be found, especially in rough or mountainous areas. Because of these conditions, the interpretation of resistivity measurements is often indefinite or uncertain and frequent correlations with known conditions should be made wherever possible.

Figure 5 shows the enormous range in resistivities encountered within the space of a few miles along the Skyline Drive. In spite of this wide range in resistivity the shape of the curve can usually be depended upon to indicate the character of the underlying material. Flat or drooping curves such as 1, 2, 5, 10, and 31, usually indicate earth or loose rock, while ascending curves such as 6, 3, 13, and 4, indicate the presence of rock. Near Front Royal, Va., some 20 miles north of Panorama, resistivity values for both soil and rock are much lower than those shown in figure 5. Earth resistivity as low as 6,000 ohm-centimeters was found at an elevation of 1,000 feet, as against values of 100,000 to 400,000 ohm-centimeters near Panorama at an elevation of more than 2,000 feet.

Rock resistivity was also found to vary over wide limits, and in one location was so low as to fail to give indication of its presence. Although not all of the 10 miles of right-of-way explored has been examined subsequent to grading, enough has been checked to prove that such tests should provide highly valuable information to bidders and contractors.

Precise classification cannot be expected but it should be possible to identify 2 and possibly 3 kinds of material, such as earth, broken or loose rock, and consolidated rock. After all, the contractor is primarily interested in knowing if he can handle the material with his shovel or whether he will need to resort to blasting. The resistivity test can give him the answer in the great majority of cases.

Curves B, C, D, and E, in figure 5, were made in an area near Washington where rock depths had been determined by a large number of test pits and borings. Curves B and D are typical of most of the area where good checks were obtained by taking the electrode spacing at the lowest point on the curve as the depth to rock. However, in a few instances curves like those shown in C were obtained. In such locations the relative resistivities of the different strata are such as to obscure the location of the rock.

Curve E was obtained at the south abutment of the Arlington Memorial Bridge where the bed rock is known to be about 35 feet from the surface. Although there is undoubtedly a great difference between the resistivity of the overlying muck and that of the rock, the sharp inflection in these curves is somewhat surprising and in strong contrast with other measurements along the Potomac River where positive identification of the rock at depths of from 40 to 70 feet has not been possible. As the changes in curvature occur in the curves representing conditions east and west of the reference point, they cannot logically be attributed to local surface conditions near the current stakes.

RESISTIVITY ABOUT A SINGLE ELECTRODE DISCUSSED

The single-electrode method of measuring earth resistivity, that has found favor with some investigators, is illustrated in figure 6. If a currrent, I, is made to flow through the earth between electrodes C_1 and C_2, we may assume that the flow of current from C_1 into a homogeneous soil will be radial if C_2 is at a comparatively great distance from C_1. With a radial flow of current from C_1 we can express the resistivity of the medium by the equation

$$\rho=191\,\frac{E}{I}\,\frac{r_1r_2}{r_2-r_1}\text{- - - - - - - - - - - - - - - - - -}(3)$$

where E is the potential drop between the two equipotential, hemispherical shells P_1P_3 and P_2P_4, and r_1 and r_2 are expressed in feet. The material for which ρ is obtained is that enveloped between the two concentric shells and designated by shading in figure 6. By progressively increasing r_1 and r_2 and measuring the potential drop, P_1P_2 or P_3P_4, a curve is obtained showing the relation of ρ to r_2. This curve will be similar to that obtained by the 4-electrode method and is supposed to indicate changes in material in the same manner, since the material included in the test has a depth equal to r_2.

As r_1 and r_2 are increased, the equipotential shells deviate more and more from a true hemisphere because the current stake C_2 is not at an infinite distance from C_1. The error introduced by the dissymmetry of the electric field about C_1 is shown by the curves of figure 7 and is seen to be greater in the direction toward C_2 than away from it. For this reason it is preferable to make potential difference measurements at P_3P_4 rather than at P_1P_2.

One advantage that has been claimed for this method of test is that the current stakes remain fixed during any depth test and therefore the results are not subject to the influence of local surface variations near the current stakes, as may occur with the 4-electrode method. In the work described here, this method was not investigated to any great extent but in the few comparative tests which have been made between the two methods, the 4-electrode method was found to give the smoother and more consistent curves.

SEISMIC METHOD BASED ON DIFFERENCES IN SPEED OF SOUND WAVES THROUGH SOIL AND ROCK

In using the seismic method of exploration advantage is taken of the wide difference in the acoustic properties of plastic and granular matter on the one hand and rigid or consolidated matter on the other. Nonrigid matter such as sand, clay, or gravel transmits wave disturbances, commonly called sound waves, at velocities of 1,000 to 6,000 feet per second, while rigid materials like

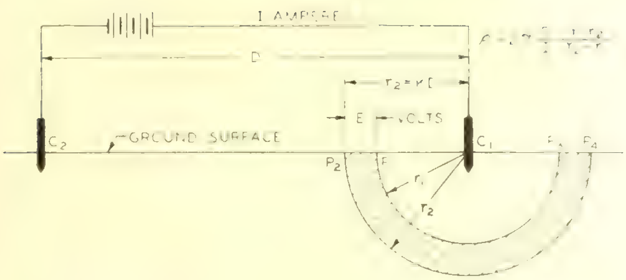


FIGURE 6.—RESISTIVITY ABOUT A SINGLE ELECTRODE.

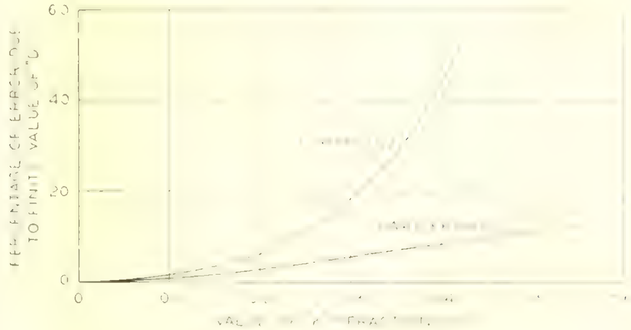


FIGURE 7.—ERROR IN SINGLE-ELECTRODE METHOD.

rock or crystalline matter transmit such disturbances at 16,000 to 20,000 feet per second. Here, then, we have a means of measuring directly that property of subsurface materials with which the engineer is concerned, namely, rigidity, while the resistivity method is used in attempts to measure this property indirectly or through its somewhat questionable relation to electrical resistivity. The seismic method is, therefore, more definite in the identification of solid rock than is the resistivity method but cannot readily be used to distinguish between clay and coarse sand or gravel, as can often be done with the resistivity method.

In view of the success with which the seismic method of exploration has been applied to oil prospecting, and in view of the fact that it is distinctly the most favored of all geophysical methods, it is somewhat surprising that it has not heretofore been adapted to relatively shallow determinations. Perhaps the reason for this is to be found in the array of apparatus and equipment ordinarily required and the cost of such operations as commonly carried out. The Oil and Gas Journal, referring to recently developed seismic reflection equipment for geophysical prospecting, says: "It consists mainly of two separate units, the recording truck and the firing car. The recording truck contains the seismometers or pick-ups (ordinarily 6), the amplifiers, and batteries, wire reels, the camera, as well as field telephone, and various other accessories. The firing car contains explosives, firing box, double reel, and telephone for cross communication with the recording truck. A drilling truck and water car are ordinarily added."

Anyone contemplating this array of cars and equipment might well question the practicability of the method as a substitute for the soil auger or other relatively simple methods of exploring shallow depths. Such equipment may be justified where the discovery of a new oil field may mean large profits to the operator but can it be applied efficiently in making less-important discoveries?

SEISMIC APPARATUS GREATLY SIMPLIFIED FOR USE IN SHALLOW WORK

It was believed that a large part of the equipment required for deep prospecting could be eliminated or greatly simplified in an apparatus designed primarily for relatively shallow work, and that a so-called "vest-pocket" model of the more extensive apparatus could be constructed to meet these requirements. The most important difference between deep and shallow exploration is the relatively short shooting distances involved in the latter and this has made the simplification of apparatus possible. Telephonic communication between shot point and recorder is not needed and most of the cumbersome wire and reels are eliminated. Only small charges of explosives are required and these can be placed in a 1¼-inch soil-auger hole, thus eliminating the heavy drilling equipment required in deep work. The short shooting distances also permit the use of less sensitive instruments and amplifying equipment is not needed.

With these modifications in mind apparatus was assembled, consisting of a 3-element oscillograph with camera for photographic recording, 3 microphonic detectors or pick-ups and two 6½-inch spools of wire. Accessories consist of 2 camp stools, one 4-foot soil auger, 4 no. 6 dry cells or a small storage battery, 1 developing tank with developing and fixing solutions, and 1 changing bag. The whole outfit, together with a crew of 3 men, can be carried in a small car and can be set up for operation in about 10 minutes.

The laborious calculations in the application of involved formulas often necessary in deeper determinations can be dispensed with where shallow structures are concerned, and in their place a simple equation substituted, requiring only a mental calculation or, at most, a slide-rule operation for its solution.

The essential units of the apparatus used are shown in figures 8 and 9. The detectors seen at the right in figure 8 are of the microphonic type and consist of four microphone buttons connected in parallel and mounted with axes vertical. The mica diaphragms have been replaced with dental rubber diaphragms that carry polished carbon disks. These lower elements of the buttons are carried on a ring that is integral with a floating inertia weight in which gravity is balanced by a helical spring about 3 inches long mounted in the vertical neck of the detector. Lateral alinement is maintained by a thin steel spider diaphragm and stops limit the vertical movement of the inertia weight to less than one-sixteenth inch. The upper element of the button consists of a conical carbon chamber with polished surfaces and containing carbon granules.

The resistance of this assembly changes enormously with the slightest disturbance, thus making it a detector of exceptionally high sensitivity. While it is subject to some of the inherent defects of the carbon microphone, it is perhaps the only type of detector that can be used in the field successfully without amplifiers. This feature makes it particularly suited to shallow exploration work where simplicity and portability are of first importance.

When in operation each detector carries a current of from 5 to 10 milliampers supplied from dry cells or a small storage battery. This current passes through the primary coil of a transformer; the secondary coil is in series with a galvanometer of the oscillograph type.

The galvanometer, therefore, responds only to a change of current in the detector.

The galvanometers are of the coil type having a direct-current sensitivity of about 4 milliamperes per inch of deflection at 10 inches and an undamped frequency of 1,200 cycles per second. The elements, carrying small reflecting mirrors, are damped in oil. An optical system directs light from a 2.5 ampere, 4-volt, straight-filament lamp to the galvanometer mirror, from where it is reflected and brought to a point focus in the plane of a moving photographic film.

Time lines on the film are obtained from "peep slits" carried on the tines of an electrically driven tuning fork that vibrates at a normal frequency of 100 cycles per second. The slits are one-half inch long and 0.01 inch wide and coincide in the neutral position of the fork and therefore give two lines for each complete cycle of the fork. The timing requires an independent lamp and optical system with the exception of the cylindrical lens (mounted immediately in front of the film) which is common to both light systems.

The camera used for moving the film is an adaptation of a Sept camera, an obsolete, amateur motion-picture camera of French manufacture, which carries a 35-millimeter film. A direct drive was substituted for the intermittent motion and other necessary changes were made. A spring motor drives the film at approximately 2 feet per second. The film attains its maximum speed almost instantly upon starting the motor and permits a record to be obtained with a film consumption of about 18 inches. A numbering lamp and two dials of perforated numbers were installed in the camera and make it possible to number films photographically from 0 to 99. This feature enables definite identification of records after development. A film cutter operated by a trigger is provided to cut the film whenever desired. As the developing tank accommodates 6 feet of film it is customary to cut the film after every third or fourth shot.

Standard, supersensitive, motion-picture film is used as it was found that less-sensitive film did not give sufficiently dense traces. Records are developed in a dark room when convenient, or in a Leitz developing tank in the field. A changing bag is needed in transferring the exposed film from the camera to the developing tank.

This equipment, with the exception of the detectors, was built in the shop of the bureau, after purchasing such items as galvanometers, tuning fork, lenses, and minor electrical supplies.

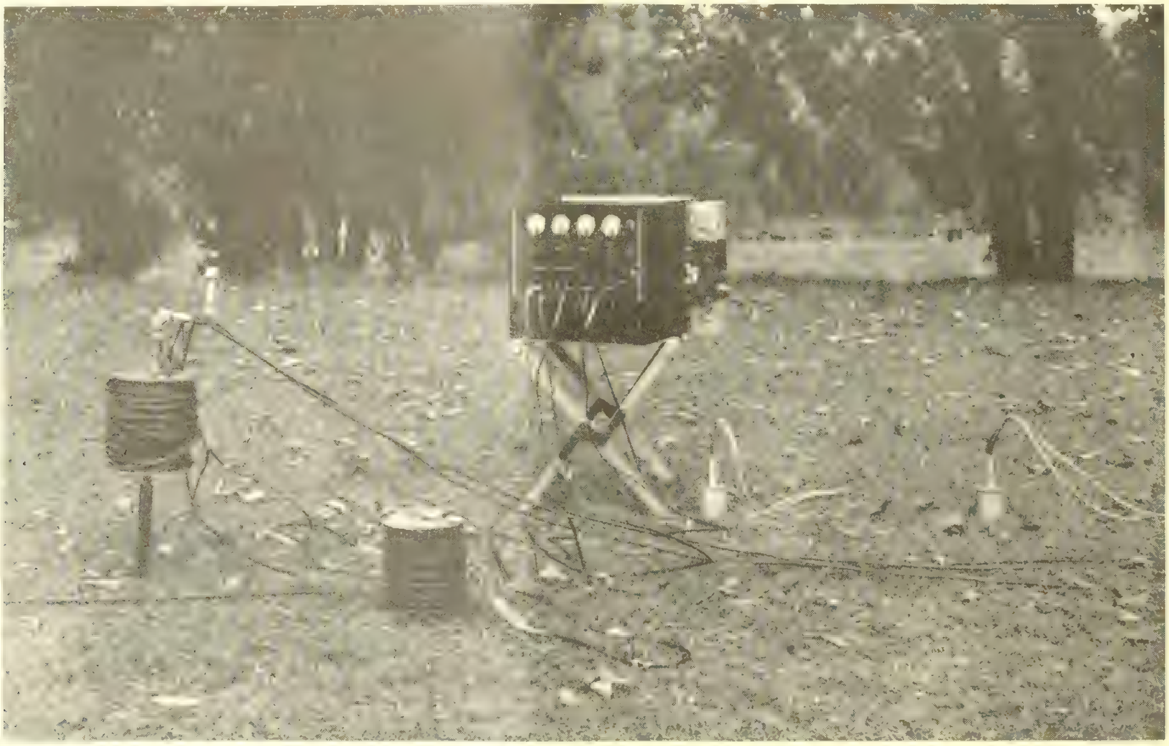


Figure 8.—Electrical Seismograph Set Up for Field Use.

DETERMINATIONS BASED ON ELEMENTARY PRINCIPLES

Two methods of seismic exploration that are in common use are known respectively as reflection shooting and refraction shooting. These terms have the same significance in geophysics that they do in optics, as the mathematical theory of transmission of sound-waves through solids and liquids is based largely on the well-known laws of optics. In reflection shooting the interpretations are based on waves that are reflected directly from different strata under investigation, while in refraction shooting it is the refracted waves that are studied. As reflection shooting is not well adapted to shallow explorations, no further space will be given to description of that technique.

The principles involved in refraction shooting are illustrated in figures 9 and 10. A blasting cap or small charge of dynamite is exploded at or under the surface of the ground at some point, S, which becomes the center of a wave disturbance that moves outward on a spherical or near-spherical front in all directions. Detectors D_1, D_2, and D_3, placed on a line passing through S, pick up this disturbance successively and carry the impulses to three galvanometers that record them as light traces on a moving photographic film.

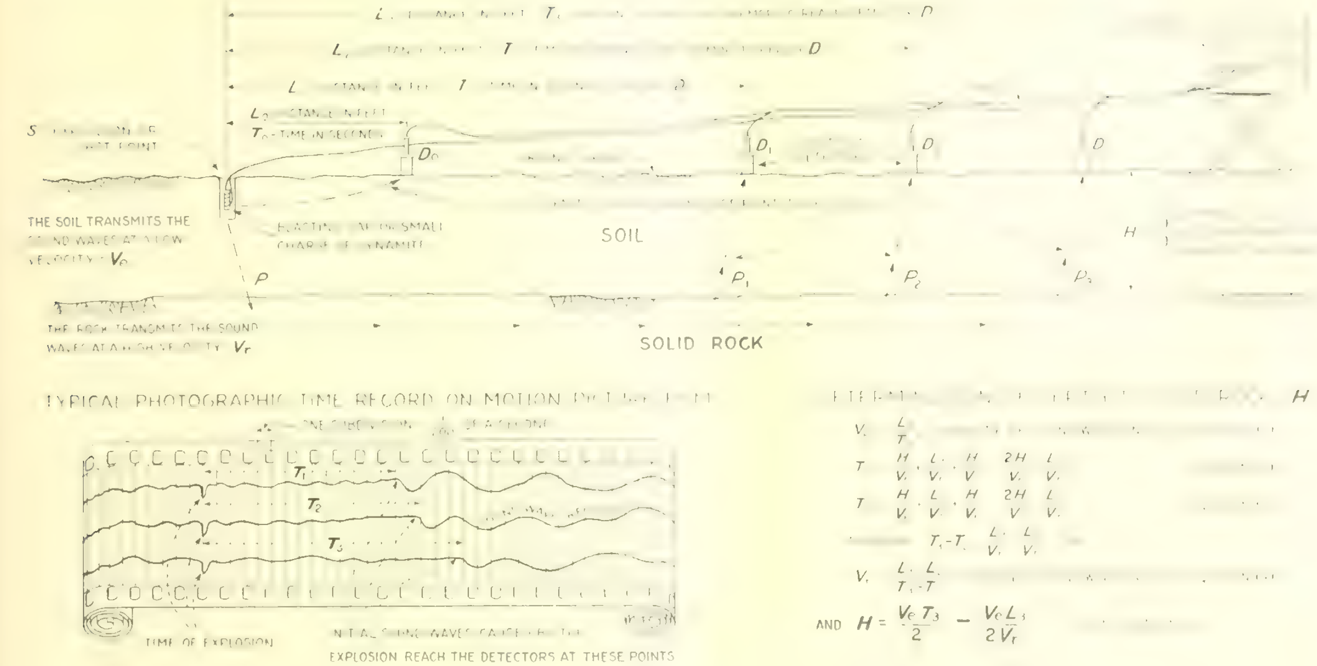

SOIL
SOLID ROCK
THE SOIL TRANSMITS THE SOUND WAVES AT A LOW VELOCITY V_e
THE ROCK TRANSMITS THE SOUND WAVES AT A HIGH VELOCITY V_r
T_0 - TIME IN SECONDS
D_0
D_1
P
P_1
P_2
P_3
H
TYPICAL PHOTOGRAPHIC TIME RECORD ON MOTION PICTURE FILM
T_1
T_2
T_3
TIME OF EXPLOSION
EXPLOSION REACH THE DETECTORS AT THESE POINTS
AND $H = \frac{V_e T_3}{2} - \frac{V_e L_3}{2 V_r}$

FIGURE 9.—SKETCH SHOWING FUNDAMENTAL PRINCIPLES OF SEISMOGRAPHIC METHOD.

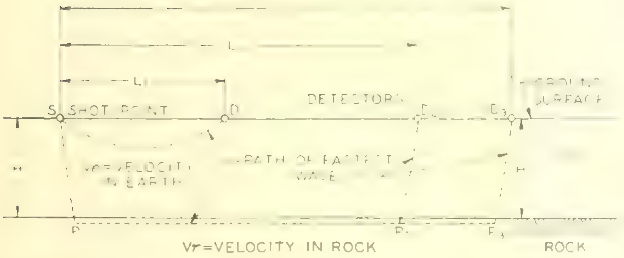


FIGURE 10.—WAVE PROPAGATION IN SEISMIC EXPLORATION.

A small wire is wound around the blasting cap and arranged so that when it is broken by the explosion an initial kick or impulse is given to the three galvanometers and the time of the explosion is thereby indicated on all three traces. As the wave front moves outward from S, its time of arrival at each of the three detectors is indicated on the moving film by disturbances in the traces as shown in figures 12, 13, and 14. By counting the number of time units between the initial kick and the arrival of the wave at each detector, it is possible to calculate the average velocity of wave propogation from shot point to each detector. From data of this kind it is usually possible to determine with a fair degree of accuracy the depth to the first strata of rigid or consolidated rock and to obtain other information of value regarding the character of the subsurface material.

Referring to figure 10, the path of the first wave to reach any detector will depend upon the ratio of the shooting distance, L, to the depth to rock, H, and also upon the relative velocities of wave propagation in the two media. If the shooting distance is relatively short, such as L_1, the path of the first disturbance to reach D_1 will be directly through the soil as indicated. The velocity of the wave through the earth can then be calculated from the equation,

$$V_e = \frac{L_1}{T_1} \qquad (4)$$

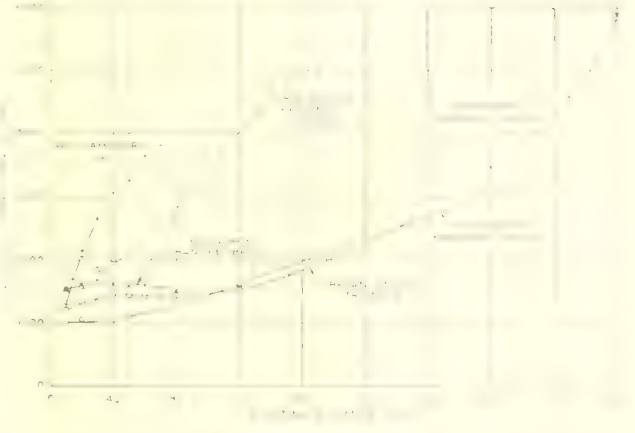


FIGURE 11.—RELATION BETWEEN VELOCITY OF SOUND WAVES THROUGH EARTH AS OBTAINED WITH THE ELECTRICAL SEISMOGRAPH.

As the shooting distance is increased, a point such as D_2 will be reached where the wave first to arrive will no longer be that going directly through the top soil but that taking the path of the refracted wave SPP_2D_2. Subsequent disturbances will reach detector D_2 by various paths but as only the first arrival can be definitely identified on the film record it is necessary to base interpretations solely on so-called "first events." Likewise the first wave to reach D_3 will be by the path SPP_3D_3. By measuring the time difference T_3-T_2 and the distance L_3-L_2 we are able to calculate the velocity of wave propagation through the rock from the equation,

$$V_r = \frac{L_3 - L_2}{T_3 - T_2} \qquad (5)$$

This relation is obvious from the fact that the time difference T_3-T_2 is taken up by the travel of the wave through the rock from P_2 to P_3, since that part of the path SPP_2 is common to both circuits.

We are now able to write the equation by which H, the depth to rock, can be calculated from known quantities. This is based on the fact that T_3, the total time of travel of the wave from S to D_3, is the sum of the combined times of wave travel over the path SPP_3D_3. Although refraction of the wave at the point P is supposed to take place at the angle of total internal refraction, we may assume with negligible error under practical conditions that this angle is 90° and that the distance PP_3 is equal to L_3. With this assumption we may write,

$$T_3=\frac{H}{V_e}+\frac{L_3}{V_r}+\frac{H}{V_e}=\frac{2H}{V_e}+\frac{L_3}{V_r} \qquad (6)$$

$$\text{or } H=\frac{V_eT_3}{2}-\frac{V_eL_3}{2V_r} \qquad (7)$$

When the distance L_3 is of such value that the direct wave through the earth reaches detector D_3 at the same time as the refracted wave, it is said to be the critical distance and we may write,

$$T_3=\frac{L_3}{V_e}=\frac{2H}{V_e}+\frac{L_3}{V_r}\text{ or}$$

$$H=\frac{L_3}{2}\left(1-\frac{V_e}{V_r}\right)\text{ and}$$

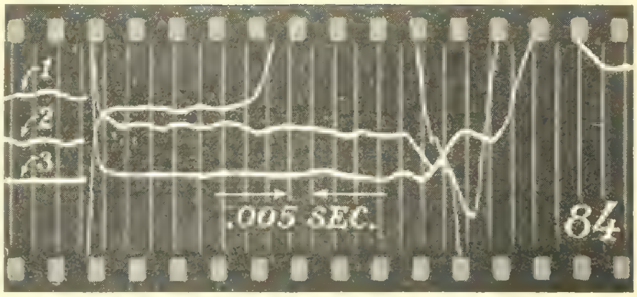
$$L=\frac{2H}{1-\frac{V_e}{V_r}} \qquad (8)$$

For best results, when determining depths to rock, L should not be greatly in excess of the critical distance. As a fairly close approximation we may say that for values of V_e and V_r usually found, $H=0.45\ L$, or $L=2.2\ H$, where L is the critical shooting distance.

Various modifications of the technique just described are sometimes necessary to determine slopes, domes, and other irregularities in underground structures. The depth to rock, H, as given in equation 7, is really the average of the depth at the shot and that at the detector. By shooting near one end of a line of detectors and then near the other end an estimate of the slope can be obtained. "Circle shooting" is another means of studying subsurface irregularities. With this method two or more detectors are placed on the arc of a circle having a radius greater than the critical distance and the shot is placed at the center. The order in which the waves reach the detectors will indicate the relative rock depths under them, the shorter time indicating the shallower rock.

Equation 5 cannot always be relied upon to give very accurate values of V_r because of the difficulty of obtaining an accurate measure of the time interval T_3-T_2 from the film record. If the detectors are placed 20 feet apart the time interval representing a velocity of 18,000 feet per second in the underlying rock will be only 0.0011 second, or a distance of about 0.0264 inch on a film moving at a speed of 2 feet per second.

It is obvious that slight differences in the performance of different detectors and errors in picking the exact time of breaks on the traces will make it impossible to determine velocities in rock by the use of closely placed detectors. Fortunately, the term in equation 7, in which V_r appears, is of minor importance, provided the shooting distance is not greatly in excess of the critical distance. For this reason an average or normal value of V_r, such as 18,000 feet per second may be assumed without fear of carrying through an error of consequence into the final value of H. Equation 7 may be used only when the shooting distance exceeds the critical distance, and this condition can usually be determined from a measure of the time intervals between detectors, even though such intervals may not give highly accurate values of velocities in rock.



CALCULATION OF DEPTH TO ROCK

SHOOTING DISTANCES, $L_1 = 50$ FEET, $L_2 = 100$ FEET $L_3 = 150$ FEET.
TIME OF WAVE TRAVEL FROM SHOT TO DETECTORS, $T_1 = .0355$ SECOND, $T_2 = .071$ SECOND, $T_3 = .074$ SECON

V_e = VELOCITY OF WAVE IN EARTH $=\frac{L_1}{T_1}=\frac{50}{.0355}=$ 1,400 FEET PER SECOND.

V_r = VELOCITY OF WAVE IN ROCK $=\frac{L_3-L_2}{T_3-T_2}=\frac{50}{.003}=$ 16,700 FEET PER SECOND

H = DEPTH TO ROCK $=\frac{V_eT_3}{2}-\frac{L_3V_e}{2V_r}=\frac{1{,}400\times.074}{2}-\frac{150}{2}\times\frac{1{,}400}{16{,}700}=$ 45.5 FEET

Figure 12.—Seismic Record and Calculations Based on Record.

FIELD TESTS GIVE SATISFACTORY RESULTS

The accuracy with which H can be determined from equation 7 will depend largely upon the value of V_e selected. In most soils the value of V_e increases with depth and the value to be substituted in the equation must therefore be intermediate between the velocity in the topsoil and that in the deeper strata. Figure 11 shows several velocity-distance curves from which values of V_e were selected in determining rock depths at the locations given. All of the curves show a distinct upward trend after the critical shooting distance is reached or, in other words, when the path of the fastest wave is through rock. At the Boundary Channel Bridge the rock is overlain with about 75 feet of spongy muck or silt and this condition is indicated by the rather flat portion of the curves within the critical distance. The same condition exists at the Bryan statue triangle and at the Memorial Bridge, in both locations the critical distance being approximately 100 feet. From the flat portion of such curves closely accurate values of V_e can be selected and equally accurate values of H obtained.

Figure 12 shows a single record from which the depth of rock at the Memorial Bridge has been calculated. The 3 detectors were spaced respectively 50, 100, and 150 feet from the shot. In this case the critical distance appears to be almost exactly 100 feet. This follows from the fact that calculations based on traces 1 and 2 result in the same velocity, thus indicating that the wave reaching P_2 could have traveled directly through the earth. However, the difference in time intervals T_3 and T_2 is such as to give a velocity of 16,700 feet per second between P_2 and P_3, which is very close to

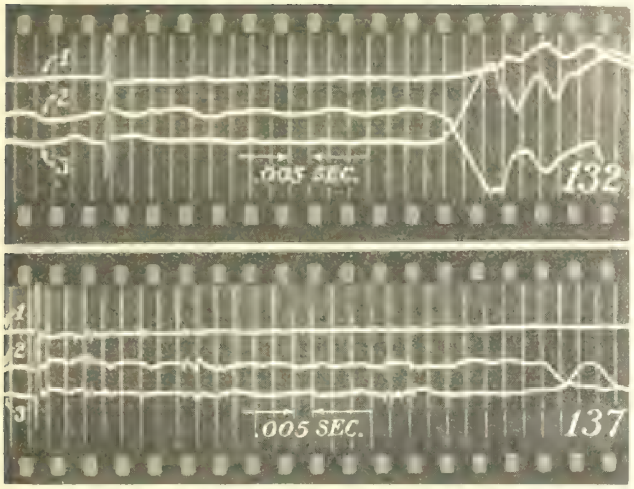


Figure 13.—Seismic Record and Calculations Based on Record.

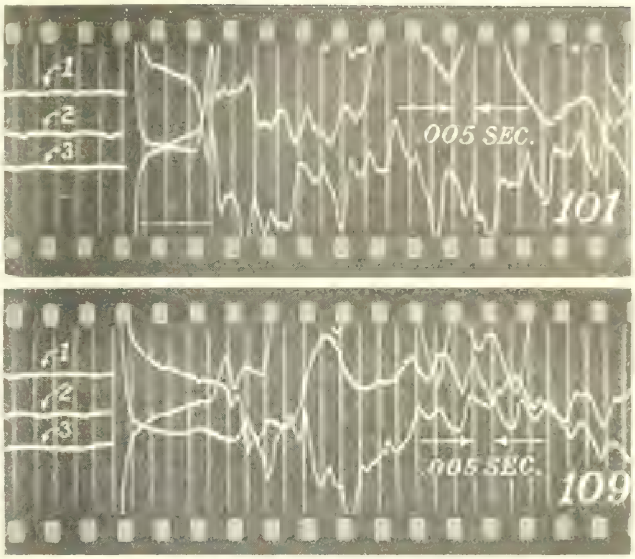


Figure 14.—Seismic Record and Calculations Based on Record.

velocity in rock. It is evident, therefore, that the time of travel to the middle detector is the same by either the direct path or the path of the refracted wave through the rock, a condition that determines the critical distance.

Figure 13 shows records from which the depth to rock at the Boundary Channel Bridge was calculated as 76 feet, a figure that checks closely with the bridge engineer's data.

DIFFICULTY SOMETIMES ENCOUNTERED IN MAKING DETERMINATIONS

Frequently the velocity curve will take the form of the curve in figure 11 that is based on tests at the Arlington experiment station. Here the critical distance is not so evident. The method by which a value of V_e was selected and the depth to rock calculated in this location will be given in detail as a typical example of a practical problem. Figure 14 shows some of the records from which depth calculations were made and table 1 is summary of all data obtained. An examination of this table shows that high velocities existed for that portion of wave travel in excess of 50 feet. Because of the very short time intervals involved and the difficulty in picking the exact breaking points on the traces and also as a result of slightly different sensitivities and characteristics in detectors, it is not always possible to obtain accurate velocities for increments in distance from which velocities in rock can be derived. It is possible, however, as in this case, to determine from the velocities if the movement is through rock and also to approximate the critical distance.

The high velocities for that portion of the travel through increments in distance at more than 50 feet from the shot enables us to select 50 feet tentatively as the critical distance. By averaging all of the over-all velocities for distances of 50 feet and less, a value of 1,834 feet per second is obtained. This is so close to the value of 1,820 feet per second derived directly from record no. 101 for a 30-foot distance that the latter was selected for V_e. Since the values of velocities corresponding to increments in distance shown in table 1 are not sufficiently consistent to justify a selection of V_r from them, a value of 16,700 is taken as fairly representative of velocity in rock. As pointed out previously, this value enters into only a minor term in the depth equation and therefore great accuracy is not so necessary in its determination as in that of V_e. With these values of V_e and V_r the value of H was computed for all distances in excess of 50 feet. The results appear in the last column of table 1, the average of which is 18.22 feet. The actual depth to rock as determined with a soil auger is 19.8 feet.

Table 1.—*Results of tests at the Arlington experiment station*

Record no.	Shooting distance, l	Time of wave travel, T	Overall velocity, V	Velocities for increments in distance, equation 5		Depth to rock H, from equation 7
	Feet	*Seconds*	*Feet per second*	*Feet*	*Feet per second*	*Feet*
97	10	0.0065	1,540	10 to 20	1,540	
99	20	.013	1,540	20 to 30	2,860	
101	30	.0165	1,820	30 to 40	2,860	
104	40	.02	2,000	40 to 50 =	5,000	
106	50	.022	2,270	50 to 60	20,000	
107	60	.0225	2,670	60 to 100	8,900	17.2
100	100	.027	3,700	100 to 120	Infinite	19.2
109	120	.0255	4,700	100 to 150 =	25,000	[illegible]
109	150	.029	5,000	100 to 180	19,700	[illegible]
109	180	.0325	5,450	60 to 180	[illegible]	[illegible]
Average						18.22

Sometimes it is necessary to make a first approximation of the depth to rock, after which a more accurate value of V_e can be selected from the velocity curve. In any event, no great error will be made in selecting a value of V_e, which is an average of all values obtained under the critical distance.

EXTRACTS FROM REPORT ON FLORIDA TRAFFIC SURVEY

CHARACTERISTICS OF TOURIST TRAFFIC AND TRANSPORTATION OF CITRUS FRUIT DISCUSSED

Reported by L. E. PEABODY, Senior Highway Economist, Division of Highway Transport

A SURVEY OF TRAFFIC on Florida State highways was conducted by the Florida State Road Department and the Bureau of Public Roads, from September 1933 to September 1934. Data were collected at 157 points in the State.[1]

The traffic on Florida highways was found to have characteristics distinct from the traffic in most States. The month of largest traffic volume is January, and September is the month of least motor travel. Seasonal variation is of small amplitude in comparison with that in many States. There is an absence of large volumes of industrial traffic; truck capacities are generally low; and tourist traffic is an important component of total motor traffic.

Seven percent of the mileage of the State highway system carries a traffic volume in excess of 1,500 motor vehicles per day; 41 percent carries a volume of from 500 to 1,499 vehicles per day; and more than half of the State highway mileage carries less than 500 vehicles per day.

Seventy-eight and two-tenths percent of the observed vehicles were passenger cars; 21.0 percent were trucks; and 0.8 percent were busses. Local vehicles, which constituted 80.3 percent of the total traffic, were distributed as follows: Passenger cars, 76.1 percent; trucks, 22.9 percent; and busses, 1.0 percent. Trucks with trailers were 5.4 percent of all trucks, four-tenths of 1 percent being foreign and the remainder were local.

Distances are long and population is concentrated within a few areas. Traffic volumes are relatively high close to the population centers and are fairly uniform between population centers. Major routes may be easily identified on the traffic-flow maps. Figure 1 shows total traffic and figure 2 shows foreign traffic. The main routes are: U S 92 from Daytona Beach to the intersection with U S 17 and from Haines City to Tampa, and Florida 64 from Tampa to St. Petersburg; U S 1 and Florida 4–A from the Georgia State line to Florida City; U S 17 from the Georgia State line to Punta Gorda; U S 90 from the Alabama State line to Jacksonville; and U S 19 from Brooksville to St. Petersburg. The routes carrying the most foreign traffic are U S 1 from the Georgia State line to Miami, Florida 64 from Tampa to St. Petersburg, U S 41 together with Florida 5 and U S 541 from the Georgia State line to Naples, and U S 92 from Daytona Beach to Tampa.

Florida's traffic history since 1925, as shown by traffic counts at 22 stations since that year, is very different from that of any other State for which data are available. This statement may be illustrated most briefly by two examples. Between 1922 and 1933 motor vehicle registration increased 140 percent in Florida and 147 percent in New Jersey; yet between 1922 and 1926 the corresponding increases were 246 percent in Florida and 90 percent in New Jersey. And again, gasoline consumption increased 228 percent in Connecticut between 1922 and 1933, as compared with 220 percent in Florida during the same period. However, gasoline consumption increases in Connecticut and Florida between 1922 and 1926 were 83 and 350 percent respectively. In view of the above it is remarkable that Florida traffic in 1932 had declined but 28 percent from its all-time peak in 1926. The first indication of a possible reversal of the downward trend in motor-vehicle registration since 1927 is given in 1934, when registration increased 20 percent over the previous year. Gasoline consumption in 1934 was more than 14 percent greater than in 1933.

TOURIST TRAFFIC ORIGINATES IN MANY STATES

Tourist traffic is smallest in May, but even in that month amounts to 70 percent of the monthly average. The common impression that tourist traffic is confined to the period of winter is incorrect; although, of course, the volume is much heavier during that period.

Nearly a quarter of the tourist traffic, excluding the traffic of tourists who spend less than 1 day in Florida, comes from that portion of the United States east of the Mississippi and north of the Potomac and Ohio Rivers. The origin of tourist traffic is shown in figure 3 in which the volume of tourist traffic originating in the areas indicated is proportional to the area of the circle shown in each area. The average travel of this group of tourists to and from their homes is in excess of 2,000 miles. More than one-half of all tourists in Florida are from Georgia and Alabama, again excluding those who spend less than 1 day within the State. More than 10 percent come from the States of Michigan, Wisconsin, Illinois, Indiana, and Ohio. The remaining tourists, approximately 20 percent, have origins scattered throughout the remainder of the country.

They stay in Florida about 1 month on the average, although there is high variation in the length of stay. Tourists who own homes in Florida make an average visit of 106 days, while those who stay with friends or relatives remain about 2 weeks. Those who rent apartments or cottages stay about 88 days; visitors who stop at hotels stay an average of 20 days; while those who occupy camps average 34 days per visit.

About 11 percent of the tourists stated that they would visit areas throughout the whole State, their answers reading typically: "Throughout the State", "everywhere in the State", "all over Florida", etc. The southeast section of Florida was the greatest attraction, nearly one-quarter of all tourists planning to visit that area.

The general routes of travel to Florida are indicated by bands of varying width in figure 3, the width representing the volume of traffic. These bands do not follow the exact location of any single route, and the traffic on two or more closely parallel routes may be shown by a single band. The increments of traffic received from each area of origin are indicated by the

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[1] The complete report is being published by the Florida State Road Department, Tallahassee, Fla. Copies are not available from the Bureau of Public Roads.

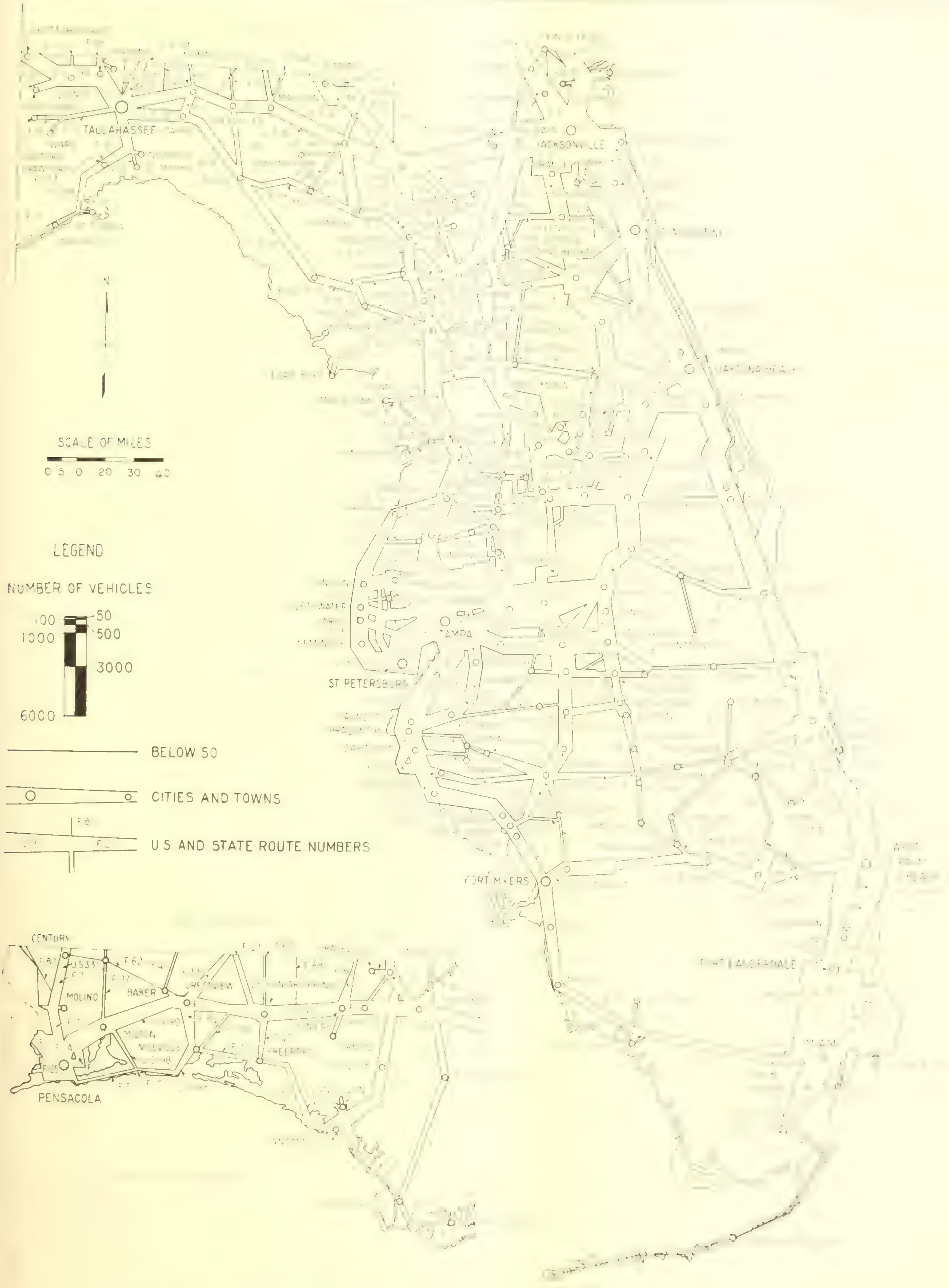

FIGURE 1.—AVERAGE DAILY MOTOR VEHICLE TRAFFIC ON FLORIDA HIGHWAYS, 1934

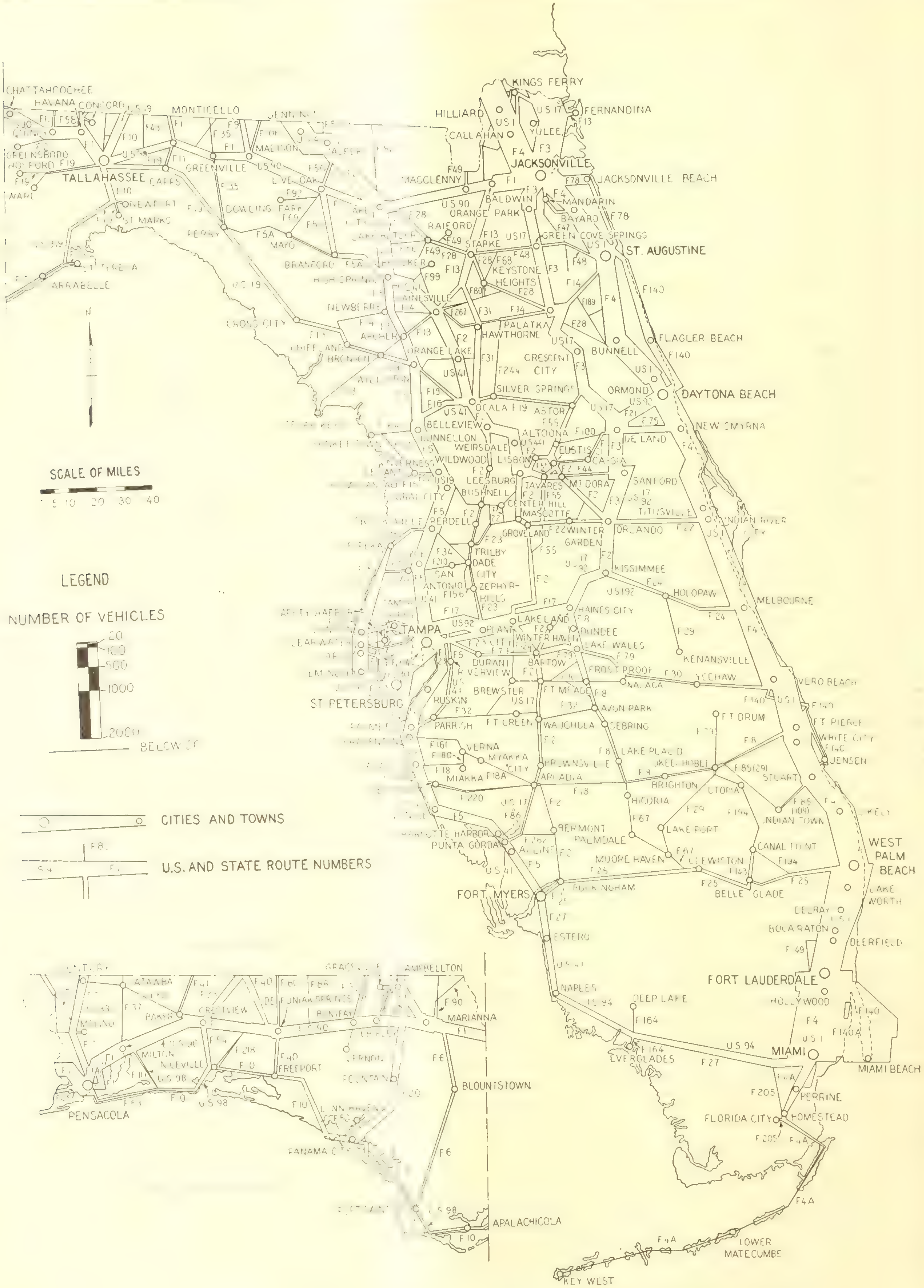

Figure 2.—Average Daily Traffic by Foreign Vehicles on Florida Highways, 1934.

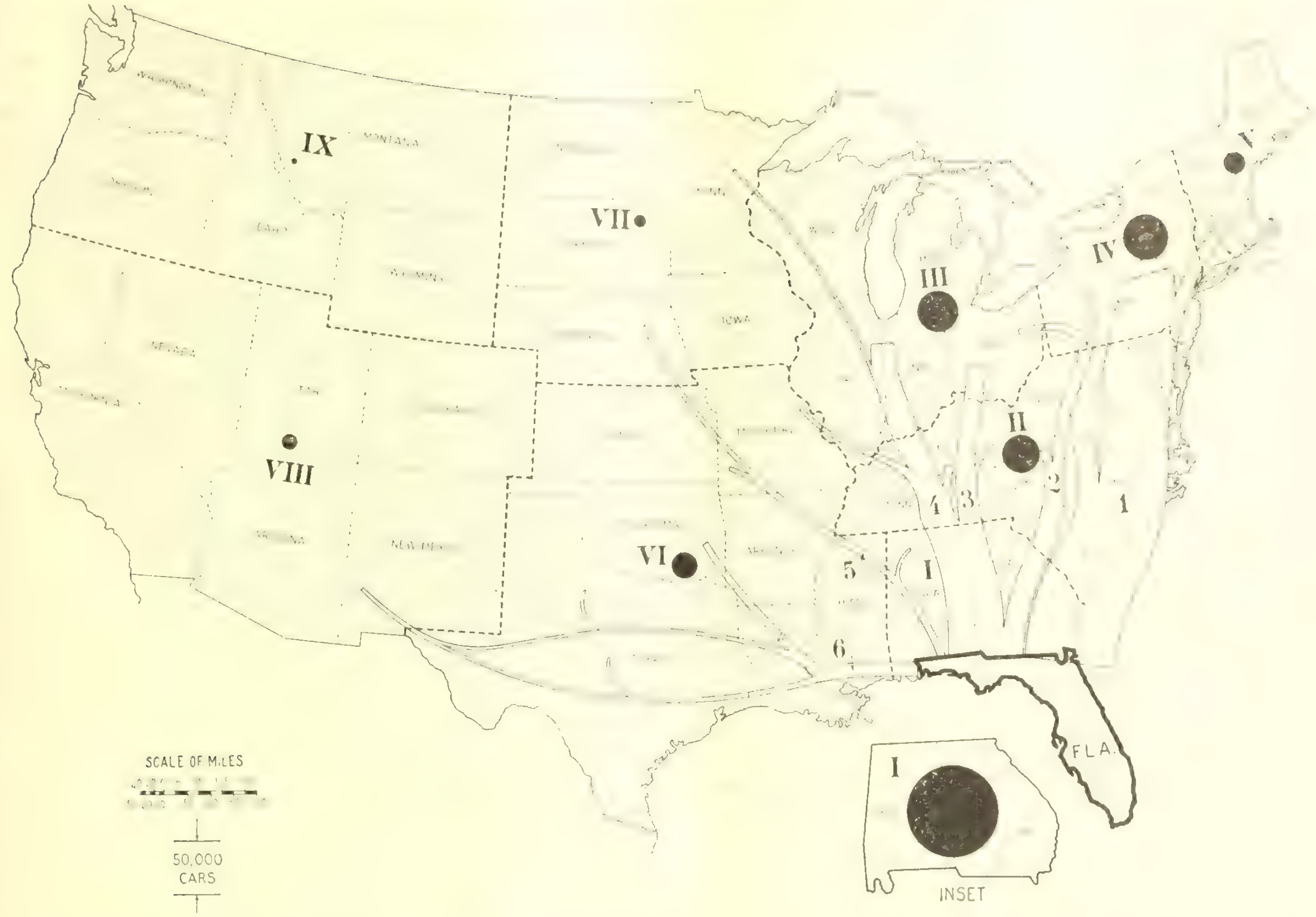

FIGURE 3.—ORIGIN OF MOTOR TOURIST TRAFFIC TO FLORIDA AND LINES OF TRAVEL. SIZE OF CIRCLE INDICATES RELATIVE NUMBER OF TOURISTS FROM EACH AREA, AND WIDTH OF BAND INDICATES THE RELATIVE VOLUME OF TRAFFIC USING EACH LINE OF TRAVEL.

increase in width of a band as it passes through that area. The traffic from area I is omitted because the volume is so large and the routes of travel are so short that an adequate graphical comparison with other areas is impossible. The preponderance of travel on the eastern coastal routes is apparent by the relative width of band 1. The principal routes included within this band are U S routes 1, 15, and 17. By far the greatest part of the traffic traveling these routes originates in New York, New Jersey, and Pennsylvania, with considerable increments from New England and from area II.

A less-popular line of travel from these same areas is indicated by band 2, which represents principally the traffic on eastern inland routes, United States routes 11, 19, 21, 29, and 41. Most of the traffic following this line originates in area II, but there is a considerable amount from area III, and an appreciable increment from area IV.

The most popular lines of travel from area III are indicated by bands 3 and 4, band 3 joining band 4 at the Georgia State line. Band 3 represents United States routes 25 and 27; and band 4 represents United States routes 31 and 41. Bands 5 and 6 indicate the lines of travel from the States west of the Mississippi River.

Contrary to what is probably the popular impression, those who gave "business" as their reason for visiting Florida constituted the largest group classified. Many people combined their business with a fishing trip, visited friends or relatives in Florida, attended sporting events, or were en route to other States.

A classification of tourist parties by type of accommodation shows that the greatest number used hotels. In this class were 162,590 parties, or 38.9 percent of the 417,960 parties staying one day or more in Florida. The next largest group, 21.0 percent, stayed with friends or relatives, 9.9 percent stopped at tourist homes, and 10.9 percent used more than one type of accommodation. These four major groups comprise four-fifths of the total. The 97,040 parties staying less than one day comprise 18.8 percent of the grand total of 515,000 parties per year.

LARGE EXPENDITURES MADE BY TOURISTS

Data with regard to the expenditures of tourists were obtained by a special investigator. Tourists were questioned as to the daily expenditure per party at times and places where they could be approached conveniently and with ample time for the investigator to satisfy himself with regard to the accuracy of the replies. The information was voluntarily given and was subject to critical questioning at the time by the investigator. Expenditures were tabulated under the general heads of "car expenses" and "other expenses." Separated under "car expenses" were the costs of gasoline, oil, garaging, and repairs incurred only during the visit. Overhead items, such as depreciation and insurance, that were not likely to be a direct expenditure in Florida, were not considered. Under "other expenses" were tabulated the items of food, lodging, and miscellaneous expenditures.

From the data obtained in this manner it was possible to compute the average party expenditures per day according to type of accommodation as presented in table 1. With the exceptions noted, these are the averages of expense items as given by a large number of separate parties, and considerable effort was made both in collecting the data and in the analysis to eliminate error and exaggeration. The replies by persons staying with friends and relatives and those using a combination of accommodations were so few in number as to throw doubt upon the correctness of average expenditures based upon them. Therefore, the expenditures tabulated for these groups were obtained by averaging appropriate items in other groups that were considered similar in characteristics. Expenditures by those staying one day were estimated in like manner as no replies were received from persons in this class.

TABLE 1.—*Itemized expenditures per party per day according to type of accommodation*

Item	Hotels	Rented cottages or apartments	Tourist homes	Camps	Own home	Friends and relatives	Combination	Less than 1 day
Persons per party	2.28	2.95	2.83	3.28	2.84	3.09	2.87	2.60
Average daily mileage per car	24	22	19	22	22	-----	-----	-----
Cost of car operation per day:								
Gasoline	$0.36	$0.32	$0.26	$0.32	$0.36	-----	-----	-----
Oil	.04	.03	.03	.03	.04	-----	-----	-----
Garaging	.23	.02	.02	-----	-----	-----	-----	-----
Repairs	.01	.02	.01	.01	.02	-----	-----	-----
Total	.64	.40	.32	.36	.42	[1] $0.54	[1] $0.54	[1] $0.54
Other expenditures per party per day:								
Lodging	3.66	1.39	1.12	.35	3.75	-----	-----	-----
Food	3.18	1.90	2.46	1.22	2.39	[2] 2.15	-----	[1] 2.23
Miscellaneous	1.33	.97	.56	.70	1.61	[1] 1.03	-----	[1] 1.03
Total	8.17	4.25	4.14	2.27	7.75	3.18	5.32	3.26
Total expenditures per party per day	8.81	4.65	4.46	2.63	8.17	3.72	5.86	3.80

[1] Average of other types.

[2] Average of food costs for those using "rented apartments" and "own home."

The daily lodging cost to parties staying at their own homes, as shown in table 1, is the estimated daily rental value of such homes. The figure, $3.75, is based upon an average value of $6,000 per home as given by the questionnaires and annual operating costs and carrying charges are assumed to equal 10 percent of value, or $600 annually. This sum is charged against a season of 160 days, or $3.75 per day.

On the basis of total daily expenditures, the two most important groups are those using hotels and home owners. Parties in these groups expended $8.81 and $8.17 per day, respectively. The parties spending the least amounts were those staying with friends and relatives, $3.72 per party per day, and the campers with an average expenditure of only $2.63 per party per day.

The information concerning type of accommodation, volume of traffic of each type, length of stay, and daily expenditures has been combined to estimate the total yearly expenditures within the State. The estimate is presented in table 2. The number of parties per year and the average length of stay for each group are shown in columns 2 and 3. The daily average party costs are repeated from table 1 in column 4. The estimate of the total yearly expenditures by each group of tourists is given in the last column. The total by all groups is $90,458,000; thus tourists are an impressive source of income to the State.

TABLE 2.—*Estimate of tourist expenditures by type of accommodation*

Stopping at—	Total cars per year	Average length of stay in days	Average cost per party per day	Expenditures per year	Percentage of total expenditures
Hotels	162,590	19.5	$8.81	$27,932,000	30.87
Apartments and cottages	22,150	87.7	4.65	9,033,000	9.98
Tourist homes	41,380	48.2	4.46	8,896,000	9.83
Camps	26,330	33.5	2.63	2,320,000	2.57
Own home	32,180	106.3	8.17	27,947,000	30.89
Friends and relatives	87.770	16.1	3.72	5,257,000	5.81
Combinations	45,560	32.6	5.86	8,704,000	9.62
Less than 1 day	97,040	---------	3.80	369,000	.43
Total	515,000	---------	---------	90,458,000	100.00

Tourists using hotels and those staying at their own homes are estimated to spend the largest amounts. The expenditures of each of these groups are nearly $28,000,000 per year, and between them they account for 62 percent, or nearly two-thirds, of the total sum spent by all tourists, and yet the number of tourists using their own homes is only 7.7 percent of all tourists. In contrast, those staying with friends are 21 percent of the total number, but their expenditures represent only 5.8 percent of the total expenditures. The contrast is even more striking in the case of trips of less than 1 day. Although 18.8 percent of the total number, they account for less than one-half of 1 percent of the total expenditure.

Table 3 gives an estimate of the direct income to the State government from tourist traffic in the form of gasoline taxes. On the average, each tourist car travels about 1,000 miles in Florida during the visit, or 515,000,000 miles for the total traffic. At 14 miles per gallon, 36,786,000 gallons of gasoline are consumed, yielding $2,575,000 at the current tax rate of 7 cents per gallon, and equivalent to approximately 16 percent of all State gasoline taxes.

TABLE 3.—*Estimate of total yearly mileage of tourist cars in Florida and payments of gasoline tax*

Average miles per car per day	22
Average length of stay per car in days	29.4
Total mileage per car per visit	647
Travel in Florida to and from destination, miles	392
Total mileage per car (round figures)	1,000
Total yearly traffic	515,000
Total yearly mileage	515,000,000
Estimated miles per gallon of gasoline	14.0
Total gallons of gasoline consumed	36,786,000
Tax per gallon	$0.07
Total tax paid by tourists	$2,575,000

TRUCK SHIPMENTS OF CITRUS FRUIT NUMEROUS

Citrus fruits, with a net farm value of approximately $37,000,000 in 1933–34, originate in an area south of a line from Palatka to Cedar Keys, largely from the sections surrounding Orlando and Leesburg, and from Sebring to Lakeland. During the season of 1933–34 the interstate truck shipments aggregated 31,590 truck

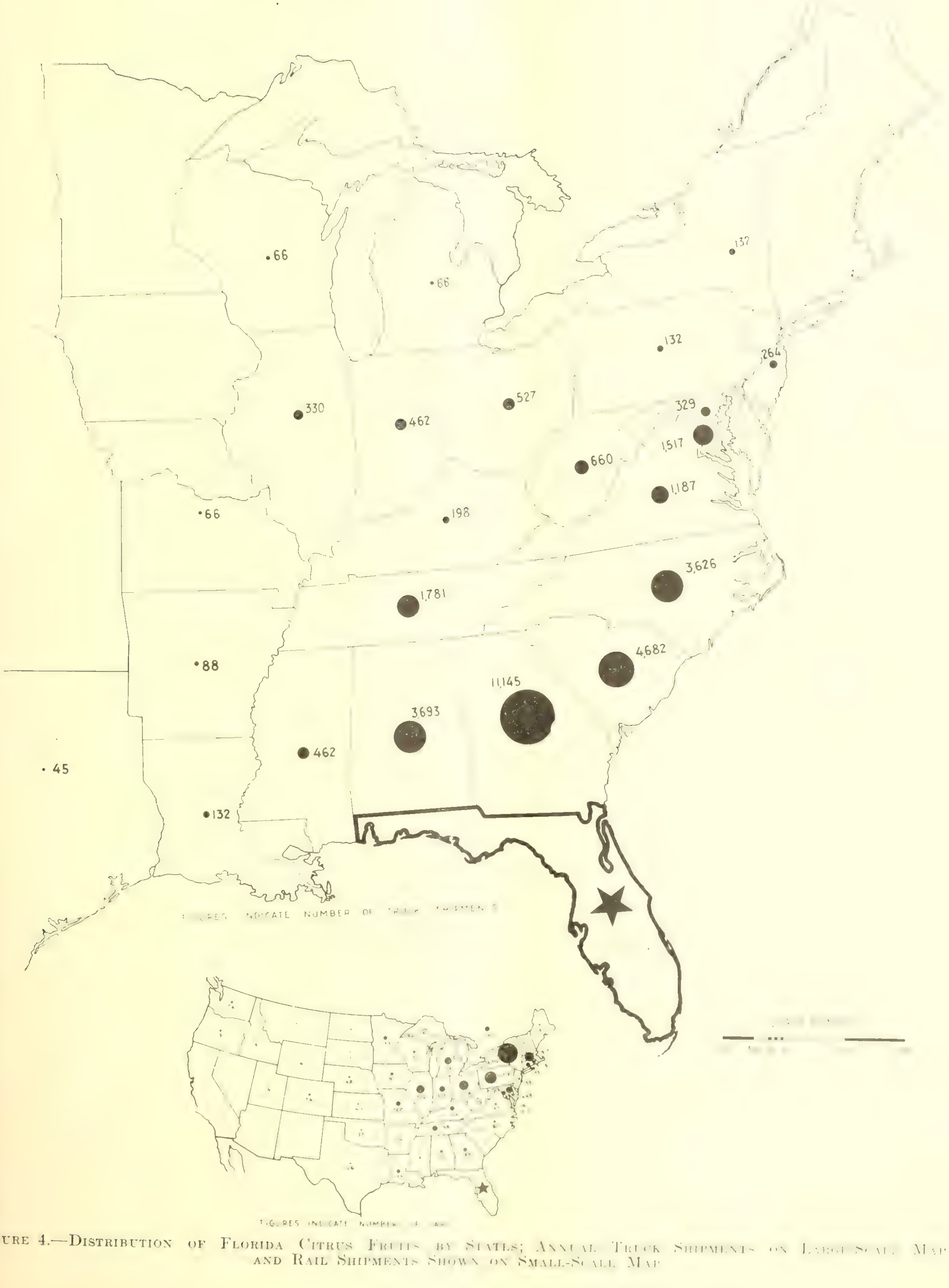

Figure 4.—Distribution of Florida Citrus Fruits by States; Annual Truck Shipments on Large-Scale Map and Rail Shipments Shown on Small-Scale Map

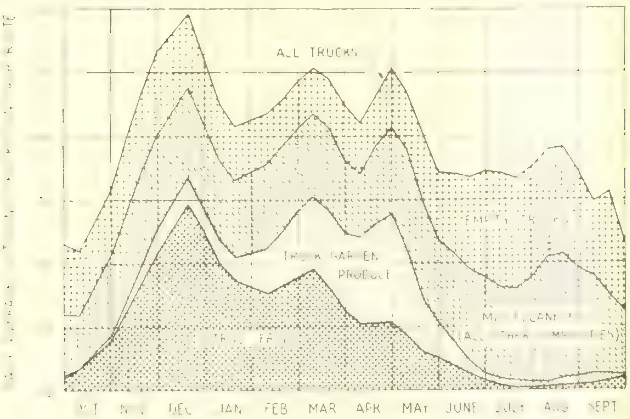

Figure 5.—Seasonal Movement of All Outgoing Trucks on the Principal Commercial Interstate Routes U S 1, U S 17, and U S 41.

loads. These truck shipments were destined mainly to Georgia, South Carolina, Alabama, North Carolina, Tennessee, the District of Columbia, and Virginia (see fig. 4), with the number of trucks in the above order. The States enumerated took about 88 percent of the total interstate truck shipments. In the total movement, all States east of the Mississippi River except the New England group and Delaware were represented, while west of the Mississippi only the States of Missouri, Arkansas, Texas, and Louisiana received truck loads of citrus fruits from Florida. Georgia and South Carolina accounted for more than half the total interstate citrus fruit shipments by truck.

The peak of the truck movement of citrus fruits is in mid-December, with a secondary peak near the middle of March. After the bulk of the fruit had been moved, many of the truckers shifted to the transportation of garden produce—beans, tomatoes, asparagus, etc.

Fifteen percent of the 215,600 outgoing trucks crossing the Florida State line during the year carried citrus fruits; 8 percent carried garden produce; 40 percent carried miscellaneous commodities; and 37 percent were empty. Figure 5 indicates the seasonal movement of these trucks and the shifting from citrus fruit hauling to the transportation of garden produce.

U S 1, U S 17, and U S 41 were the major gateways through which these commodities moved, these three routes together carrying 82 percent of all citrus fruit shipped to other States by truck and 82 percent of the interstate garden-produce shipments.

More than 80 percent of all trucks crossing the State border and carrying citrus fruit was registered in States other than Florida. Seventy-one percent of trucks carrying garden produce in interstate commerce was also registered in other States.

Fifty-two percent of all trucks used in the carrying of citrus fruit had capacities of 2 to 4 tons; 40.5 percent were in excess of 4 tons; while 7.5 percent had capacities up to and including 1½ tons. The use of trailers was negligible, since less than 2 percent of all trucks hauled trailers.

The internal movement of citrus fruit was largely to packing plants and canneries at Tampa and Jacksonville.

(Continued from p. 67)

The velocity curve obtained at Williamsburg, Va., figure 11, applies to a marl and shell conglomerate overlain by a few feet of clay. The velocities found are relatively high for a location where there is no rock near the surface and are the result of the highly compacted shell conglomerate which appears to have about the same acoustical properties as a deep clay or shale.

A few tests have been made at quarry sites and at other locations where solid rock is found within a few feet of the ground surface and all indicate that the depth of such overburdens can be determined quickly, definitely, and accurately by the seismic method. For such work a single no. 8 blasting cap gives ample energy, thus reducing the cost of explosives to a negligible amount.

While the work of the bureau with the seismograph has been largely experimental and limited to one locality, the results to date have been so promising that they leave little doubt as to the ultimate value of this tool in the study of subsurface formations.

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 5,910,559	$ 3,207,195	$ 35,889	321.6	$ 2,469,521	$ 689,465	$ 1,235,363	142.7	$ 35,462	$ 283,727	13.7	$ 15,632	$ 574,942
Arizona	3,878,555	1,338,712	4,813,746	3,741,188	410,963	335.7	1,070,577	99,279	867,223	59.3		51,395		38,088	9,131
Arkansas	3,334,167	1,714,000	3,204,323	2,497,443	182,638	157.1	1,998,007	658,284	1,025,049	86.7	158,919	203,155	28.2	19,521	303,159
California	7,912,928	3,713,643	9,850,132	7,198,859	160,700	294.2	4,086,820	712,709	2,223,795	124.6		696,073	24.5	1,360	633,075
Colorado	3,437,265	2,424,504	4,310,032	3,321,549	879,368	210.5	1,745,017	110,498	1,527,416	76.6				5,218	17,720
Connecticut	1,404,213	607,500	797,613	795,279		14.5	1,451,228	608,934	579,726	23.4					27,774
Delaware	877,566	461,697	1,052,958	868,470	177,572	42.1	292,719	4,973	274,892	6.8	4,082	7,442		40	1,792
Florida	2,469,370	1,116,600	3,079,015	2,211,915	61,384	117.9	973,060	191,660	731,244	33.8	17,087	99,228	4.1	48,707	224,743
Georgia	5,045,592	2,556,745	4,112,681	3,620,465	255,697	290.8	2,605,165	1,280,056	1,242,086	128.0	6,394	332,032	9.8	138,678	726,930
Idaho	2,166,858	1,131,910	2,072,442	1,967,735	35,916	183.0	783,026	192,495	577,668	48.8				6,628	518,326
Illinois	4,408,827	2,408,778	2,203,523	2,141,079	19,269	38.6	4,030,041	2,254,193	1,775,848	66.3	3,000	414,494	2.8	10,555	199,167
Indiana	5,918,921	2,816,687	3,494,046	3,396,228		111.4	3,328,565	1,496,941	1,796,409	144.7	77,951	931,062	42.4	47,801	89,216
Iowa	5,027,830	2,217,361	4,801,249	4,637,430	78,520	288.6	2,657,630	390,400	2,021,869	146.2		66,260	4.6		50,712
Kansas	5,044,802	2,354,131	5,649,117	4,949,300	564,871	609.3	1,898,343	86,912	1,743,637	152.8		45,623	1.7	8,590	
Kentucky	3,751,605	1,302,209	3,594,656	3,314,189	33,571	243.6	1,025,867	384,396	565,267	82.9		552,258	21.9	53,020	151,113
Louisiana	2,693,135	1,380,419	2,085,146	2,296,812	19,599	76.6	1,600,583	343,350	1,103,969	28.1	36,405	17,157	1.3	16,568	239,694
Maine	1,567,012	782,195	1,351,182	1,310,906	10,497	44.3	796,215	248,494	547,721	12.9		223,977	7.1	7,612	
Maryland	1,782,263	289,609	862,107	791,495	70,360	15.5	948,151	797,232	150,919	21.3				193,536	68,330
Massachusetts	1,101,716	1,632,874	1,425,641	1,032,666		37.4	937,996	52,687	833,487	12.5		162,525	7.7	16,363	636,862
Michigan	6,051,532	3,226,284	4,988,486	4,719,527	81,400	225.1	3,680,300	1,284,500	2,381,000	146.0		554,275	26.3	47,506	209,609
Minnesota	4,561,011	2,642,244	5,707,670	4,241,696	1,308,545	905.0	946,579	179,056	748,922	120.9	67,882	316,705	45.8	72,377	268,071
Mississippi	3,489,337	2,832,182	4,814,705	2,470,565	298,408	248.0	2,892,110	849,964	1,354,716	157.6	124,882	728,687	49.6	43,925	450,370
Missouri	5,237,532	2,132,426	4,748,082	4,209,249		189.8	3,034,479	950,949	1,855,140	92.8		277,286	12.2	77,334	
Montana	4,463,849	2,714,208	6,073,696	4,459,720	1,116,367	509.0	1,499,590	4,129	1,393,384	127.1		189,850	.2		14,606
Nebraska	3,914,481	1,982,182	5,148,343	3,875,799	137,284	369.4	2,111,098	25,639	1,730,423	100.2		42,563	5.1	13,043	71,913
Nevada	2,909,387	1,350,356	3,172,505	2,668,146	433,021	302.7	876,158	202,644	672,847	119.4	17,735	14,755	2.6	20,863	229,733
New Hampshire	692,119	465,404	638,684	612,389		10.8	542,872	79,730	441,404	12.5					24,000
New Jersey	3,173,019	951,379	1,757,402	1,733,583		31.6	1,973,510	1,405,336	330,958	18.7		269,816	2.3	34,100	350,606
New Mexico	2,846,648	1,676,769	3,501,414	2,760,948	596,536	344.4	963,212	85,700	806,618	64.8					273,615
New York	10,465,672	3,748,600	10,599,201	8,686,358	181,330	214.4	8,532,593	1,630,019	3,313,880	146.9		48,500		149,295	204,890
North Carolina	4,761,147	1,930,365	4,809,411	3,499,965	382,833	590.0	1,418,881	873,383	356,624	158.5	139,906	463,108	23.5	247,893	727,799
North Dakota	2,902,224	1,469,484	3,203,886	2,617,060	139,940	1,064.5	635,579	59,883	406,526	239.8	65,660	248,512	132.1	159,620	674,505
Ohio	7,277,758	3,539,256	7,447,532	7,040,880	16,500	191.4	3,397,860	131,720	2,924,090	71.7	102,798	8,720	1.9	2,360	589,946
Oklahoma	4,608,399	2,342,590	4,593,178	4,098,690	361,341	311.6	2,033,637	498,548	1,322,575	83.2	10,032	520,949	22.9	1,130	137,725
Oregon	3,053,448	1,452,741	3,599,415	2,964,300	279,947	193.9	1,169,203	80,590	988,992	49.5		114,860	5.8	8,558	68,942
Pennsylvania	6,691,194	4,554,082	6,414,620	5,716,391	431,666	132.8	5,018,561	915,718	3,882,969	87.1	2,126	42,824	1.1	56,959	196,[illegible]
Rhode Island	979,367	474,772	968,005	899,627		20.5	560,592	79,740	464,572	14.3					[illegible]
South Carolina	2,729,583	940,954	2,398,609	2,260,483	73,571	204.5	763,691	374,583	389,108	66.2	58,706	27,998	2.4	35,311	[illegible]
South Dakota	3,005,739	1,523,821	2,804,444	2,236,171	90,724	477.8	1,332,729	598,726	719,345	257.4	113,454	592,081	93.7	57,339	[illegible]
Tennessee	4,246,309	2,105,453	4,827,144	4,001,356	184,679	189.0	1,454,956	176,547	1,182,008	46.8	9,488	556,213	20.2	58,917	[illegible]
Texas	11,588,543	6,852,253	12,030,113	11,143,481	324,664	1,043.8	5,646,433	389,255	5,057,564	424.3	39,390	494,338	41.0	16,017	[illegible]
Utah	2,167,205	1,066,345	3,014,382	2,324,852	476,525	258.5	637,029	37,000	437,550	44.5				5,355	[illegible],271
Vermont	928,184	466,042	980,588	911,663	28,464	47.9	381,556	10,670	342,862	17.5		80,224	2.2	[illegible]	14,492
Virginia	3,731,207	1,916,178	3,875,327	3,367,890	263,498	160.9	1,634,505	225,730	1,288,777	68.0	111,491	286,762	25.9	26,096	77,141
Washington	3,057,934	1,553,206	2,880,403	2,620,512	198,794	101.0	1,676,270	402,011	1,153,679	28.4		63,666	.6	35,411	[illegible]
West Virginia	2,013,405	1,140,167	1,933,571	1,847,329	60,892	71.2	716,607	111,669	588,046	25.4	44,371	120,340	4.7	10,[illegible]	170,35[illegible]
Wisconsin	4,697,518	1,818,970	4,454,970	4,108,641	108,084	211.6	1,720,357	571,758	1,141,389	75.3	182	525,799	20.2	16,937	43,535
Wyoming	2,250,663	1,686,368	2,593,040	2,064,553	365,110	507.9	1,326,472	182,391	1,117,914	204.6		157,540	20.4	3,718	47,804
District of Columbia															
Hawaii	1,693,344	598,778	842,001	526,724		19.3	1,334,240	1,155,109		20.3				11,511	598,778
TOTALS	185,258,236	93,539,354	190,091,595	157,938,751	10,936,937	12,581.0	94,610,190	24,175,655	59,517,470	4,488.1	1,247,90[illegible]	10,331,279	732.5	1,54[illegible],327	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF MAY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,389,928	$1,064,961	$1,805,744	$1,723,041	$81,263	43.2	$831,673	$623,453	$208,220	27.8	$29,878	$141,553	2.3	$13,555	$633,924
Arizona	807,982	305,191	660,221	607,495	37,305	13.5	73,734	20,000	49,172	1.1	129,322	46,328	.4	51,165	172,386
Arkansas	1,964,534	857,025	1,740,924	1,602,739	38,070	43.5	543,041	248,967	292,772	9.5	101,076	243,955	6.0	11,752	282,228
California	4,213,986	2,219,360	4,287,179	3,459,880	235,750	53.8	2,411,082	739,196	1,363,382	16.9		448,244	3.6	14,909	171,984
Colorado	1,718,633	190,000	1,789,097	1,676,118	19,122	37.1	150,288		150,288	2.9				42,515	20,589
Connecticut	802,407	426,500	839,791	802,407	9,448	10.2	137,740		137,740	1.2		143,909	1.7		135,403
Delaware	460,409	230,849	513,762	460,282	44,973	7.2	19,786		19,786	.6		25,019	1.3	127	141,072
Florida	1,459,648	501,200	1,831,478	1,432,802	102,827	21.4	36,542		36,542	.4	2,898	118,227	1.0	23,948	243,604
Georgia	2,724,620	1,278,373	1,661,049	1,628,661		61.2	1,219,848	880,012	332,848	27.0		273,610	6.0	215,946	671,915
Idaho	1,197,829	321,126	1,156,126	1,110,647	2,643	19.4	260,483	45,372	213,923	2.0				41,810	104,560
Illinois	7,381,910	2,230,350	6,416,149	6,122,778		66.4	2,045,568	1,202,054	843,514	8.4	47,260	826,271	5.9	9,813	560,564
Indiana	4,287,050	2,136,306	3,157,872	3,034,021		63.6	1,648,669	1,073,165	573,040	19.7	148,115	1,250,478	20.8	31,750	312,789
Iowa	2,614,472	1,311,000	2,031,920	1,891,868	58,385	54.9	1,401,252	721,565	591,315	21.1	1,000	236,235	6.0	39	425,065
Kansas	2,522,401	1,432,949	2,596,805	2,368,811	69,641	40.4	1,385,846	105,232	1,265,311	15.3	48,358	97,997	2.6		
Kentucky	1,927,828	958,599	1,416,588	1,359,618	6,477	31.9	910,129	525,577	374,701	10.1	30,000	209,802	3.8	12,634	367,619
Louisiana	1,708,577	744,560	738,751	702,860	34,048	19.0	1,227,120	921,988	263,091	17.2	78,986	202,426	3.7	4,742	244,996
Maine	960,426	484,379	835,187	828,794		16.4	146,823	47,071	99,752	1.2	83,948	287,118	4.7	613	97,509
Maryland	891,132	452,515	390,127	384,134		4.1	1,075,978	262,457		.9				244,541	452,515
Massachusetts	5,007,199	847,600	2,143,777	2,102,233		13.4	3,131,554	2,876,372	230,206	5.8		38,077	.7	28,595	579,317
Michigan	3,500,638	1,613,142	3,275,133	3,051,933	104,400	38.8	1,657,700	412,750	1,207,050	14.8	14,950	105,950	4.5	21,005	195,742
Minnesota	3,719,143	1,421,494	3,337,320	3,056,375	232,957	109.9	1,174,799	594,748	485,569	17.5	7,446	23,172	2.4	60,574	679,796
Mississippi	1,744,669	354,022	911,650	853,044	45,338	28.5	967,675	750,135	142,478	27.4	75,757	49,444	4.8	65,734	116,762
Missouri	4,019,501	1,617,451	2,932,657	2,842,548	18,791	51.6	1,241,575	1,038,609	157,129	11.5		63,870	2.5	138,345	1,377,661
Montana	1,115,962	113,092	1,055,202	1,025,115	19,551	33.2	87,990	34,716	28,720	5.1	52,838	24,534	5.2	3,292	40,287
Nebraska	1,957,240	991,091	2,246,830	1,936,925	277,481	39.9	576,603		576,603	9.8		385		20,314	136,621
Nevada	500,051	100,000	479,800	473,901		9.4	57,842		57,842	1.4				26,150	42,158
New Hampshire	740,335	242,465	721,984	668,776	49,851	15.9	131,823	71,559	60,055	3.0		50,935	.3		81,624
New Jersey	3,117,921	1,809,500	2,495,361	2,370,700		21.4	1,440,610	641,265	637,318	6.6		112,071		105,956	1,060,111
New Mexico	1,674,158	529,506	1,646,988	1,466,891	180,097	39.0	192,758	123,326	69,432	2.9	4,129			79,812	279,977
New York	8,255,661	3,756,621	6,998,680	6,355,868	299,400	56.0	4,975,591	1,707,167	3,049,290	30.2	109,000	56,000		83,626	351,931
North Carolina	2,380,573	1,210,236	2,385,032	2,131,966	245,003	82.9	749,064	124,691	585,870	22.1	91,217	240,487	4.3	32,699	138,876
North Dakota	1,451,112	734,741	1,026,608	1,018,678	488	43.5	356,678	228,144	128,534	13.9	178,323	207,424	23.3	25,967	398,296
Ohio	4,335,686	2,359,503	4,508,267	4,014,713	19,045	57.8	1,977,700	226,500	1,624,800	21.7	93,352	259,500	3.2	1,121	456,158
Oklahoma	2,304,200	1,171,295	2,031,211	1,868,393	90,980	43.0	970,052	398,185	568,682	13.0	35,871	207,009	3.2	1,752	304,623
Oregon	1,526,724	867,977	1,592,770	1,457,414	98,304	31.2	614,701	66,635	529,562	10.1	518	150,263	1.1	2,157	89,849
Pennsylvania	4,854,988	2,397,703	4,351,774	4,016,398	173,720	60.9	1,972,561	766,131	1,083,439	21.6		509,211	2.9	72,459	631,333
Rhode Island	579,625	285,760	519,889	518,991		7.4	141,760		141,760	1.5				60,634	144,000
South Carolina	1,364,791	488,000	1,059,855	1,057,656		33.8	342,849	241,028	101,821	12.7	66,107	173,892	4.7		212,287
South Dakota	1,502,870	761,911	1,075,741	1,074,535	808	35.9	273,640	125,314	148,326	8.9	82,190	47,015	6.7	220,830	565,762
Tennessee	2,123,155	1,121,790	1,799,440	1,698,233	82,163	25.1	770,370	413,851	356,519	7.2	11,071	380,060	4.1		303,047
Texas	6,642,863	1,795,000	5,197,710	5,004,861	71,446	119.8	2,051,576	1,344,149	531,064	28.8	52,836	499,112	11.6	241,017	693,378
Utah	778,826	533,173	777,754	649,146	65,566	20.2	407,329	129,131	255,800	7.4		136,000	4.5	550	75,806
Vermont	500,509	240,611	454,392	390,966		11.9	262,696	97,248	142,046	4.8		70,326	1.9	12,296	28,239
Virginia	1,948,780	956,021	1,474,921	1,284,889	155,231	27.9	1,225,477	559,193	411,337	9.7	93,321	252,387	8.6	11,377	137,066
Washington	1,977,260	776,603	2,112,269	1,922,046	168,152	37.2	536,852	48,798	488,054	9.4		98,273	.9	6,415	22,125
West Virginia	1,342,270	570,085	1,017,690	967,807	13,293	16.5	374,171	344,863	29,308	5.4	29,600	137,058	4.0		390,427
Wisconsin	2,596,143	1,379,513	2,554,532	2,406,862	78,912	53.6	639,474	113,025	526,449	10.9		734,402	10.0	76,255	39,750
Wyoming	1,125,332	29,416	988,667	982,691	2,784	22.5	155,723	141,009	14,132	3.0				1,632	12,500
District of Columbia	946,445	181,051	877,332	696,281	181,051	6.5	250,164	250,164		.2					
Hawaii															
TOTALS	115,668,402	48,401,616	97,920,006	90,563,791	3,414,764	1,801.8	45,234,959	21,284,815	21,184,592	531.6	1,699,367	9,178,029	185.2	2,120,429	14,624,231

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3 PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 1,268,086	$ 1,197,828	$ 68,712	96.3	$ 1,352,044	$ 781,826	$ 570,218	87.6		$ 157,593	16.7	$ 52,799	$ 268,437
Arizona	525,423	998,032	684,085	516,393	139,878	56.8	695,428	9,030	603,790	58.8		138,677	13.2		115,687
Arkansas	1,449,634	857,024	1,229,021	1,222,992		149.0	499,805	152,568	345,790	60.5		322,316	47.2	74,073	188,918
California	[illegible]	1,999,203	3,590,636	2,984,134		164.3	1,652,915	494,605	1,021,274	53.4		518,401	15.8	1,700	459,528
Colorado	1,718,632	871,502	2,097,119	1,605,435	203,213	193.5	964,260	110,000	579,563	118.4	$ 3,197	88,726	1.2		
Connecticut	659,120	420,868	173,170	160,281	12,889	3.5	727,514	498,839	222,880	16.0					185,099
Delaware	481,113	230,849	351,392	218,550	126,792	39.9	349,959	262,563	81,793	26.5		18,000	5.0		4,264
Florida	1,302,816	1,043,543	1,576,683	1,281,312	282,574	85.5	542,598		542,598	32.0		209,434	12.2	21,504	8,937
Georgia	2,320,973	1,278,373	1,477,337	1,458,407		114.1	949,375	666,924	282,451	66.3	125,944	241,247	20.3	69,699	754,676
Idaho	1,121,562	824,450	1,325,270	1,097,735	56,671	156.1	593,003		566,655	67.6				23,827	[illegible]
Illinois	[illegible]	4,282,273	2,594,437	2,519,751		146.7	6,076,129	3,244,268	2,831,861	310.1	9,848	1,131,282	42.4	6,166	319,130
Indiana	731,872	135,970	408,547	385,193		44.1	373,819	310,433	63,386	49.3		46,391	6.4	36,245	26,192
Iowa	2,413,358	1,590,000	2,398,676	2,061,174	272,800	369.6	1,681,499	351,527	1,150,575	268.3		166,500	62.3	707	[illegible]
Kansas	[illegible]	[illegible]	[illegible]	2,085,242	135,727	226.5	1,567,974	381,253	1,186,721	86.4	43,499	8,147	1.6	12,407	
Kentucky	1,837,926	1,557,503	1,926,248	1,715,113	102,480	221.3	1,375,238	107,202	1,223,516	[illegible]		170,563	23.3	15,611	[illegible]
Louisiana	1,426,879	[illegible]	[illegible]	[illegible]	44,008	49.1	584,819	260,030	324,789	26.6	127,387	441,009	22.9	28,084	29,146
Maine	842,479	[illegible]	1,095,891	842,404	169,334	87.2	282,154		244,708	19.1		8,259	.5	76	22,711
Maryland	[illegible]	[illegible]	[illegible]	781,556	8,290	57.5	510,846	99,746	411,100	26.3		176,376	2.6	9,830	472,168
Massachusetts	488,185	[illegible]	477,470	469,741		15.2						576,837	15.9	18,444	293,163
Michigan	3,184,057	1,613,142	3,024,656	2,849,679	16,400	205.6	1,661,177	305,527	1,360,750	74.9		203,225	13.3	28,851	32,767
Minnesota	2,376,415	[illegible]	2,579,294	2,134,840	[illegible]	288.5	1,162,065	[illegible]	887,962	106.6		111,515	6.9	26,131	46,211
Mississippi	1,744,669	354,023	1,040,267	1,040,267		111.4	653,430	636,930	16,500	59.4	24,601	110,538	17.1	42,870	226,984
Missouri	2,923,273	2,423,863	2,952,588	2,666,006	190,245	634.4	1,665,691	235,551	1,384,887	275.2		753,022	138.5	1,716	95,709
Montana	1,859,937	942,434	2,008,378	1,758,063	245,842	256.4	536,560		536,560	48.6	55,249	139,455	14.3	46,626	20,577
Nebraska	1,957,240	991,091	2,396,387	1,957,240	426,115	415.1	464,470		464,470	73.5		16,291	.3		84,214
Nevada	1,136,479	852,000	1,425,415	1,113,353	265,765	179.2	317,541		317,541	30.7				23,125	248,674
New Hampshire	477,785	261,593	571,184	448,385	77,387	28.3	149,959	29,000	116,979	8.0		67,227	1.7		
New Jersey	[illegible]	[illegible]	56,528	55,099		.5						111,963	1.7		348,037
New Mexico	[illegible]	[illegible]	1,328,048	1,235,193	[illegible]	229.4	590,218	36,931	553,287	67.4		43,346	1.9		45,942
New York	[illegible]	[illegible]	3,469,145	3,035,560	80,589	36.8	4,713,570	515,500	3,438,850	281.5		92,900	8.2	[illegible]	[illegible]
North Carolina	[illegible]	[illegible]	[illegible]	2,124,767	246,495	268.2	1,350,592	223,812	1,128,780	137.2		143,100	12.8	31,394	181,965
North Dakota	[illegible]	734,742	[illegible]	[illegible]	[illegible]	[illegible]	365,418	[illegible]	62,291	[illegible]	128,054	196,749	98.7	61,069	449,325
Ohio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	302.0	1,434,476	82,310	[illegible]	99.5		159,500	7.3	[illegible]	[illegible]
Oklahoma	[illegible]	1,171,095	[illegible]	1,913,305		255.7	1,367,750	385,117	818,313	62.3		181,547	15.7	5,777	[illegible]
Oregon	[illegible]	777,036	1,818,833	[illegible]	161,282	128.4	[illegible]	[illegible]	610,028	42.9		5,780	3.1	27,563	
Pennsylvania	7,344,822	[illegible]	[illegible]	6,221,554	129,575	545.6	[illegible]	1,123,268	[illegible]	209.2		37,780	3.1		[illegible]
Rhode Island	479,716	254,040	449,748	439,716		33.2	212,562		212,562	6.7		[illegible]	1.4		[illegible]
South Carolina	[illegible]	1,340,000	[illegible]	[illegible]		115.5	1,299,438	239,531	[illegible]	149.0	49,827	274,346	[illegible]	[illegible]	[illegible]
South Dakota	[illegible]	[illegible]	[illegible]	1,134,346	[illegible]	[illegible]	[illegible]	318,624	215,341	[illegible]		[illegible]	[illegible]		[illegible]
Tennessee	[illegible]	[illegible]	1,589,371	1,533,502		123.7	971,497	[illegible]	423,710	[illegible]	[illegible]	[illegible]	21.9	[illegible]	[illegible]
Texas	[illegible]	[illegible]	[illegible]	[illegible]	167,508	[illegible]	[illegible]	[illegible]	[illegible]	211.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Utah	[illegible]	[illegible]	1,312,327	[illegible]	[illegible]	195.4	479,682	94,022	314,373	71.1		[illegible]	[illegible]		[illegible]
Vermont	[illegible]	[illegible]	[illegible]	[illegible]	28,424	37.4	226,279		210,028	[illegible]				[illegible]	[illegible]
Virginia	[illegible]	[illegible]	[illegible]	[illegible]	21,440	[illegible]	[illegible]	97,473	[illegible]	[illegible]	59,710	[illegible]	[illegible]		[illegible]
Washington	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	67.7	[illegible]		688,372	[illegible]					[illegible]
West Virginia	[illegible]	[illegible]	[illegible]	[illegible]		41.9	664,891	[illegible]	[illegible]	[illegible]		[illegible]	4.4	[illegible]	[illegible]
Wisconsin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Wyoming	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	313,414	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	78.1		[illegible]
District of Columbia	[illegible]	[illegible]	[illegible]	[illegible]	166,491	10.2	[illegible]		[illegible]	2.7					[illegible]
Hawaii	[illegible]	[illegible]	[illegible]	177,718		4.9									[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	77,667,975	[illegible]	8,317.5	51,676,820	[illegible]	[illegible]	4,101.6	[illegible]	[illegible]	471.1	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 8,984,389	$ 6,128,064	$ 185,854	461.1	$ 4,653,237	$ 2,094,743	$ 2,013,801	258.1	$ 65,340	$ 582,874	32.7	$ 81,986	$ 1,477,303
Arizona	5,211,960	2,641,935	6,158,052	4,865,076	588,146	405.9	1,339,739	128,309	1,520,185	119.2	129,322	236,400	13.6	89,253	297,204
Arkansas	6,748,335	3,428,049	6,174,268	5,323,174	220,708	349.6	3,040,353	1,059,819	1,663,611	156.7	259,995	769,426	81.4	105,346	774,305
California	15,607,354	7,932,206	17,727,947	13,642,874	396,450	512.2	8,150,817	1,946,511	4,608,451	194.9		1,662,718	43.9	17,969	1,264,587
Colorado	6,874,530	3,436,006	8,196,248	6,603,102	1,101,703	441.1	2,859,565	220,498	2,257,268	197.8	3,197	88,726	1.2	47,733	38,309
Connecticut	2,865,740	1,454,868	1,810,574	1,757,967	22,337	28.3	2,316,482	1,107,773	940,346	40.6		143,909	1.7		348,276
Delaware	1,819,088	923,395	1,918,112	1,547,303	349,337	89.2	662,464	267,536	376,470	33.8	4,082	50,460	6.3	167	147,128
Florida	5,231,834	2,661,343	6,487,177	4,926,030	446,785	224.9	1,552,201	191,660	1,310,385	66.2	19,986	426,889	17.4	94,159	477,284
Georgia	10,091,185	5,113,491	7,251,066	6,707,532	255,097	466.1	4,774,388	2,826,992	1,857,384	221.3	132,338	846,888	36.1	424,323	2,153,521
Idaho	4,486,249	2,277,486	4,553,838	4,176,117	95,230	358.5	1,636,512	237,867	1,358,246	118.5				72,265	824,010
Illinois	17,570,770	8,921,4[illegible]1	11,174,109	10,783,608	19,269	251.7	12,151,738	6,700,514	5,451,224	384.8	60,108	2,372,047	51.0	26,540	1,073,861
Indiana	10,037,343	5,088,[illegible]63	7,060,466	6,815,442		219.1	5,351,053	2,880,539	2,432,835	213.7	226,065	2,227,931	69.6	115,796	428,197
Iowa	10,055,660	5,115,361	9,231,845	8,590,422	409,705	713.1	5,740,381	1,463,492	3,763,759	435.6	1,000	468,995	72.9	746	475,902
Kansas	10,089,604	5,117,675	10,469,748	9,403,352	770,235	876.2	4,852,163	573,397	4,195,669	254.5	91,857	151,767	6.0	20,397	
Kentucky	7,517,359	3,818,311	6,937,492	6,388,919	142,528	496.8	3,311,233	1,017,175	2,163,484	257.8	30,000	932,623	49.0	81,265	579,676
Louisiana	5,828,591	2,963,932	4,486,025	4,010,450	97,655	144.7	3,412,522	1,525,368	1,691,849	71.9	242,779	660,592	28.0	49,994	513,836
Maine	3,369,917	1,711,586	3,282,260	2,982,103	179,831	147.9	1,225,192	295,565	892,181	33.1	83,948	519,354	12.3	8,301	120,220
Maryland	3,564,527	1,810,058	2,084,612	1,957,185	78,650	77.2	2,534,975	1,159,435	562,019	48.5		176,376	2.6	447,907	993,013
Massachusetts	6,597,100	3,350,474	4,046,888	3,604,640		66.1	4,069,549	2,929,059	1,063,693	18.3		777,439	24.3	63,402	1,509,342
Michigan	12,736,227	6,452,568	11,288,275	10,621,138	202,200	469.5	7,019,177	2,002,777	4,948,800	235.7	14,950	863,450	50.0	97,362	438,118
Minnesota	10,656,569	5,425,551	11,624,285	9,492,911	1,857,669	1,303.4	3,283,443	929,248	2,122,412	245.1	75,328	451,392	55.2	159,082	994,078
Mississippi	6,978,675	3,540,227	6,766,622	4,363,876	343,747	387.8	4,513,214	2,237,029	1,513,694	244.4	225,241	888,670	71.4	152,529	794,116
Missouri	12,180,306	6,173,740	10,633,326	9,737,803	209,036	875.8	5,941,746	2,225,109	3,397,156	379.5		1,094,178	153.2	217,395	1,473,370
Montana	7,439,748	3,769,734	9,137,276	7,242,898	1,381,760	798.6	2,124,140	38,846	1,958,664	180.8	108,087	353,840	19.6	49,918	75,470
Nebraska	7,828,961	3,964,364	9,791,560	7,769,964	840,880	824.4	3,152,171	25,639	2,771,497	183.6		59,239	5.5	33,357	292,748
Nevada	4,545,917	2,302,356	5,077,720	4,255,400	718,806	491.3	1,251,542	202,644	1,048,230	151.6	17,734	14,755	2.6	70,138	520,565
New Hampshire	1,909,839	969,462	1,931,852	1,729,551	127,238	55.0	824,654	180,288	618,438	23.5		118,162	2.0		105,624
New Jersey	6,346,039	3,220,879	4,309,291	4,159,382		53.5	3,414,120	2,046,600	968,276	25.3		493,850	4.0	140,056	1,758,753
New Mexico	5,792,935	2,941,700	6,476,449	5,463,037	869,483	612.9	1,746,188	245,957	1,429,337	135.1	4,129	43,346	1.9	79,812	599,534
New York	22,330,101	11,327,921	21,067,027	18,077,786	561,319	357.2	18,221,754	3,852,687	9,802,020	458.7	109,000	197,400	8.2	290,629	767,182
North Carolina	9,522,293	4,840,941	9,569,731	7,756,698	874,331	941.1	3,520,537	1,221,886	2,071,274	317.8	231,123	846,696	40.6	312,586	1,048,640
North Dakota	5,804,448	2,938,967	5,215,765	4,594,602	166,205	1,409.6	1,357,675	591,154	597,351	355.5	372,037	652,685	254.1	246,656	1,522,726
Ohio	15,484,592	7,865,012	15,944,007	14,760,489	60,545	551.2	6,810,036	440,530	5,852,693	193.0	196,150	427,720	12.4	87,423	1,524,054
Oklahoma	9,216,798	4,685,180	8,665,053	7,880,388	452,321	610.2	4,371,439	1,281,849	2,709,569	158.5	45,902	909,505	41.8	8,659	613,784
Oregon	6,106,896	3,097,814	7,011,018	5,901,350	539,533	353.5	2,485,199	166,751	2,128,582	102.5	518	270,909	10.0	38,278	158,791
Pennsylvania	18,891,004	9,590,788	17,273,851	15,954,343	734,960	739.2	10,554,882	2,805,117	7,300,454	317.9	2,126	589,815	7.1	129,418	965,559
Rhode Island	1,998,708	1,014,572	1,937,642	1,858,334		61.1	914,914	79,740	818,895	22.5		36,815	1.4	60,634	158,862
South Carolina	5,459,165	2,770,954	4,520,114	4,379,226	73,571	353.7	2,405,978	855,142	1,513,215	227.9	174,641	476,237	40.1	50,157	707,931
South Dakota	6,011,479	3,047,643	5,115,500	4,495,052	139,683	872.3	2,140,235	1,042,564	1,083,012	418.4	195,644	985,503	189.2	278,219	839,445
Tennessee	8,492,619	4,302,991	8,216,555	7,233,092	266,842	337.8	3,156,823	1,098,178	1,962,243	99.2	25,062	1,266,412	46.2	136,286	807,494
Texas	24,244,024	12,291,253	23,811,226	22,107,957	563,618	1,943.7	10,042,235	1,749,921	7,916,317	664.3	110,726	2,049,189	108.2	275,420	1,762,129
Utah	4,194,708	2,132,691	5,104,463	3,928,652	734,891	474.1	1,524,040	260,153	1,007,723	123.0		161,000	7.4	5,903	229,077
Vermont	1,867,573	948,007	1,955,715	1,739,753	56,887	97.2	870,531	107,918	696,936	38.1		150,550	4.1	19,902	43,634
Virginia	7,416,757	3,765,387	7,005,733	6,222,366	440,219	400.5	3,488,558	882,397	2,230,131	138.5	274,521	739,018	53.5	37,473	356,019
Washington	6,115,867	3,106,412	6,108,162	5,623,231	374,000	205.9	2,908,994	450,809	2,330,105	86.7		161,939	1.5	41,826	240,369
West Virginia	4,474,234	2,280,335	3,696,691	3,516,406	74,185	129.6	1,755,669	868,628	870,149	55.9	73,971	356,037	13.0	15,229	979,964
Wisconsin	9,724,881	4,941,837	9,356,561	8,674,021	235,580	435.6	3,869,373	943,244	2,716,774	141.9	182	1,745,614	36.1	107,434	243,869
Wyoming	4,501,327	2,287,712	4,721,255	4,094,704	442,577	684.0	1,795,609	350,526	1,418,331	248.0	50,747	323,123	98.5	5,350	103,681
District of Columbia	1,918,469	973,842	2,015,847	1,668,305	347,542	16.7	587,789	250,164	337,625	2.8					288,674
Hawaii	1,871,062	949,778	1,020,210	704,442		24.2	1,334,240	1,155,109		20.3				11,511	949,778
TOTALS	394,000,000	200,000,000	374,403,898	326,220,517	19,049,762	23,200.3	191,521,969	59,214,856	116,262,763	9,121.3	3,657,836	29,822,463	1,888.8	4,906,791	34,865,012

CLEMSON COLLEGE
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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 5 JULY 1935

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

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BUREAU OF PUBLIC ROADS

Volume 16, No. 5 July 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CLEMSON
GOVERMENT PUBLICATION

MICROCHEMICAL EXAMINATION OF SOIL SOLUTIONS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by JAMES A. KELLEY, Junior Highway Engineer

SOILS for highway purposes are tested to determine the characteristics indicative of their performance as road surfaces, bases for thin wearing courses, subgrades, and as foundations for retaining walls, bridges, and similar structures. Information on physical properties such as stability, compressibility, elasticity, and capillarity is generally sought. In such determinations soil is assumed to consist of inert solids of constant volume and containing pores that enlarge and shrink as the soil mass changes in volume.

This assumption is not strictly true as soluble materials, organisms, and bacteria are usually present, although not in sufficient amounts to require consideration in the interpretation of the results of physical tests.

The character and amount of the soluble soil constituents may have an important bearing upon such problems as the durability of concrete and the selection of admixtures for use in the stabilization of soils. But accurate, quantitative, chemical analyses of soil solutions are difficult to make, even by the most elaborate methods. After some investigation it has been found that a comparatively simple and more or less qualitative microchemical method may be useful in analyzing soil solutions.

SOIL MOISTURE CONTAINS MINERAL MATTER IN SOLUTION [1]

According to the soil scientist the mineral constituents of soils are products of the disintegration and degradation of rocks. However, due to mixing and transporting agencies, more minerals are likely to be present than those furnished by the rocks from which a soil is primarily derived. Even in beach sand it is surprising how many minerals other than quartz can usually be found. Hence there is the generalization that practically every soil contains all of the common rock-forming minerals.

Aside from silicon and iron oxide, the principal soil minerals are silicates, ferro-silicates, alumino-silicates, or ferro-alumino-silicates of the common bases—sodium, potassium, calcium, magnesium, and ferrous iron. Other bases such as lithium, barium, or the heavy metals may occasionally be present in appreciable amounts as may other types of silicates or other mineral salts.

The silicates or silico minerals are all somewhat soluble in water, and, being salts of weak acids with strong bases, they are greatly hydrolyzed. A convenient illustration is afforded by the well-known rock and soil mineral, orthoclase, that with alteration may become kaolin. The reaction of orthoclase with water may be represented as follows:

$$KAl\,Si_3\,O_8 + HOH \rightleftarrows H\,Al\,Si_3\,O_8 + KOH$$

Under ordinary soil conditions, with a relatively large proportion of carbon dioxide in the soil atmosphere, the potash formed would be more or less completely transformed to the bicarbonate as follows:

$$KOH + CO_2 + H_2O \rightleftarrows KHCO_3 + H_2O$$

Unless the hydrolysis of a silicate of the alkalis or alkaline earths is a reversible action, no minerals containing silicon could persist in the soil for any length of time and all soils would soon become sterile wastes composed essentially of quartz, kaolin, and ferruginous oxides. It has been suggested that the original mineral particles are protected from decomposition by a jelly-like coating on the surface of the soil grains.

If a soil be shaken up thoroughly with water, the resulting solution filtered free of suspended matter and then boiled to eliminate the carbon dioxide, generally the solution will give an alkaline reaction. This is true also of the waters of most springs, ponds, or creeks. However, the mineral content of such waters varies widely. The water that passes down through the larger interstices of the soil is not long in contact with the individual soil particles and floccules, and, because diffusion of dissolved mineral substances is quite slow especially in dilute solutions, it takes up but little matter from such aqueous films as it may intercept.

Different conditions govern the action of the soil water that returns towards the surface by capillary action to form the great, natural, nutrient medium for plants. This water moves slowly over the soil particles in films. It is in contact with successive fragments of any particular mineral and with all the different minerals making up the soil for long periods of time. Consequently, it tends to become a solution saturated with the minerals encountered.

Many attempts have been made to extract and analyze solutions naturally existing in the soil. The results obtained have not been very satisfactory, mainly because solution in a soil, under conditions suitable for crop growth, is held by a force of great magnitude 9,000 to 15,000 atmospheres.

By means of powerful centrifuges it has been possible to obtain from soils small quantities (a few centimeters at a time) of dilute solutions containing about 6 to 8 parts per million of phosphoric acid (P_2O_5) and 25 to 30 parts per million of potash (K_2O). The analysis of a few cubic centimeters of a very dilute solution is in itself very difficult, necessarily involving uncertainty as to the value of the results.

Wheat, corn, and some common grasses have been grown to a satisfactory maturity in tap water having a concentration of seven parts per million of potassium and one-half part per million of phosphoric acid. In this connection, investigators believe that the ratio of potassium to phosphoric acid of 14 to 1 is quite important. Wheat, grasses, cowpeas, vetches, potatoes, and other plants have been grown satisfactorily in solutions made by shaking up a soil in distilled water and separating the solution from the solid particles with an unglazed porcelain filter.

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[1] The material under this heading is summarized from the text book, The [illegible] tion by Frank K. Cameron, U. S. Bureau of Chemistry and Soils. The [illegible] Publishing Co., Easton, Pa., 1911, and Williams and Norgate, 14 Henrietta Street, Covent Gardens, London, England

MANY DIFFERENT MATERIALS FOUND IN SOIL SOLUTIONS

Some idea of the kinds and quantities of soluble constituents of soils is furnished by analyses of plant ashes and waters from springs, lakes, and rivers. Analyses of ashes of ordinary crops are given in table 1.[2] In presenting these data attention is called to the fact that plant physiologists and soil scientists are divided into different schools. One group maintains that plants do not dissolve significant quantities of minerals that would otherwise remain undissolved; another school emphasizes the important role that the root exudations exercise in this connection.[3]

Table 1.—*Chemical composition of ashes of ordinary crops*

Crops	Potash and soda alkali	Magnesia	Lime	Phosphoric acid	Silica	Sulphuric acid	Chlorine
Cereals:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Grain	30	12	3	46	2	1.5	1
Straw	12–27	3	7	[illegible]	50–70	2.5	2
Legumes:							
Kernel	44	7	5	[illegible]	1	4	2
Straw	27–41	7	25–39	8	5	[illegible]	6.7
Root crops:							
Roots	60	[illegible]	6–12	8–18	1.4	5–12	3–9
Tops	37	3–16	10–35	3–8	3	6–13	7–17
Grasses in flower	43	4	8	8	37	4	5

Table 2 from Hilgard [4] contains data on the chemical composition of river waters. Additional analyses are given in table 3. Table 4, also from Hilgard, affords some insight into the actual and possible solvent effects of water in the soil.

Authorities agree that it seems impossible to exhaust a soil's solubility by successive leachings with water. This was demonstrated in 1863 and 1864 by Ulbricht [5] and by Schultze [6]; their general conclusions were corroborated by King [7] in 1904.

King's first leaching experiments were made by shaking up the soil sample with 10 times its dry weight of water for 3 minutes, then determining the ingredients of the filtrates by very delicate (mostly colorimetric) methods. The soil was dried at 120° C. between successive leachings. At each drying not only is the soluble matter again drawn to the surface but heating a soil renders additional amounts of soil ingredients soluble in both water and acids. (See Hilgard.)

Table 2.—*Chemical composition of river waters*

	Potash and soda	Magnesia	Lime	Phosphoric acid	Silica	Sulphuric acid	Chlorine
	Parts per million	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*
Yukon (Alaska)	8	[illegible]	30		8	9	0.4
St. Lawrence (Pointe des Cascades)	8	10	17	Trace	[illegible]	18	2.6
Missouri (Montana)	32	18	58	0.22	14	22	18.0
Mississippi (near Carrollton, La.)	20	11	41	.	[illegible]	16	10.0
Rio Grande (Fort Craig, N. Mex.)	11	2	23	......	10	47	36.0

WATER-SOLUBLE SOIL CONSTITUENTS HAVE POSSIBLE INFLUENCE ON THE DURABILITY OF CONCRETE STRUCTURES

At the eleventh annual meeting of the Highway Research Board, it was suggested that disintegration of concrete could be of three types; chemical, part chemical and part physical, and physical.[8]

The purely chemical type of disintegration results from such causes as contact with sea water, alkali, sodium and magnesium sulphates, various acids found in ground waters and sewage, or the many chemical compounds of a greater or less stability that under certain conditions may be set up in the hydration of cements.[9] The detrimental chemical, whether in soil or water, must be present in sufficient amount to produce a readily discernible action. Such action involves base exchange and would be expected to begin where the concrete is in contact with the detrimental agency and to progress from this location toward the interior of the structure. In road slabs detrimental action of this type would begin at the bottom and progress upward.

It is assumed that in the physico-chemical type of disintegration, the active chemical is either in solution in water that enters the slab by capillary movement or is dissolved by moisture contained within the structure. It is then deposited at some location on the interior of the structure where the rate of percolation changes, or at the surface where evaporation occurs. This theory serves to explain why piers, piles, and similar structures, immersed in water with chemical content obviously too low to injure the completely immersed portions of the structure, may, by continued capillary flow and evaporation, accumulate enough chemicals just above the water line to be detrimental. The theory also serves to explain the deterioration of pavement slabs that begins at the top and works downward.

The purely physical type of disintegration results from the growth of crystals without chemical action. The crystals may be formed by the freezing of water or by the crystallization of dissolved chemicals due to the evaporation of the liquid carrier.[10] This, like the physico-chemical type of disintegration, can be expected to begin at the surface of freezing or evaporation and to progress toward the interior of the slab.

Figure 1 illustrates the manner in which soil solutions are assumed to travel vertically through road slabs in order that crystals may be deposited at the tops of the slabs. The rate of travel depends upon the permeability and this is controlled more by the character of voids than by their percentage in the mortar. Fine cracks that are almost invisible to the eye afford more or less continuous channels to the surface and greatly increase the permeability.

It is well known that disintegration progresses more rapidly in natural rocks that contain cracks and laminations than in those that do not. In experiments on the phenomenon of crystal growth, Professor Taber[11] found that such materials as brick, cement mortar, and pottery also were less resistant to disintegration when containing small fissures.

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[2] From the text book How Plants Grow by Samuel W. Johnson, Orange Judd Company, New York, 1908, page 171.

[3] See The Feeding Power of Plants by Walter Thomas. Plant Physiology, vol. 5, No. 4, October 1930.

[4] The text book Soils by Eugene Woldemar Hilgard. The MacMillan Co., New York, 1916, and The MacMillan Co., Ltd., London.

[5] Die Landwirtschaftlichen Versuchs-Stationen, vol. V, 1863, p. 207.

[6] Die Landwirtschaftlichen Versuchs-Stationen, vol. VI (1864), p. 11.

[7] Proceedings of the 25th Annual Meeting of the Society for the Promotion of Agricultural Science (1904), p. 171–190.

[8] Functions of Steel Reinforcement in Concrete Pavements and Pavement Bases, by C. A. Hogentogler and E. A. Willis. Proceedings Eleventh Annual Meeting, Highway Research Board, 1931, page 299.

[9] The Durability of Concrete by C. H. Scholer. Proceedings Tenth Annual Meeting, Highway Research Board, 1930, page 132.

[10] The Mechanism of Corrosion of Portland Cement Concrete with Special Reference to the Role of Crystal Pressure, by F. O. Anderegg, 1929. Proc. A. C. I., vol. 25, 1929.

[11] Frost Heaving, by Stephen Taber. The Journal of Geology, vol. 37, No. 5, July–August 1929, p. 440.

TABLE 3.—*Results of water analyses* [1]

Sample no.	Source	[illegible]	Potassium and sodium	Magnesium	[illegible]	[illegible]	[illegible]	[illegible]	Chlorine
			Parts per million	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	[illegible]	[illegible]
1	Spring	Paris, Maine	27	16	[illegible]	27	[illegible]	[illegible]	[illegible]
2	do	Caledonia, N. Y	102	30	[illegible]		[illegible]	[illegible]	[illegible]
3	Well	Washington, D. C	6	1	[illegible]			[illegible]	
4	do	Alexandria, Va	10	[illegible]	[illegible]				
5	Spring	Loudoun County, Va	84	17	[illegible]	[illegible]		[illegible]	
6	do	Virginia Hot Springs, Va	22	[illegible]	[illegible]	[illegible]		[illegible]	
7	do	Towesville, N. C	29	9	151	[illegible]		[illegible]	[illegible]
8	Well	Charleston, S. C	[illegible]	8	14	[illegible]	[illegible]	[illegible]	[illegible]
9	Surface drainage	St. Augustine, Fla	74	17	[illegible]			52	[illegible]
10	Well	Clinton, Mo	132	[illegible]	[illegible]		[illegible]	[illegible]	
11	Spring	Mountain City, Tenn	8	2	[illegible]				
12	Well	Frankfort, Ky	181	19	[illegible]		[illegible]	187	[illegible]
13	Spring	Lemsboro, Ill	300	147	542	113	[illegible]	3,004	[illegible]
14	do	Nashville, Ill	681	277	[illegible]	1,142	12	1,695	[illegible]
15	Well	Story City, Iowa	19	32	[illegible]	219	Trace		
16	Spring	Thurman, Mo	3	3	[illegible]			[illegible]	
17	do	Magnet Cove, Ark	4	Trace	69			[illegible]	
18	do	Sulphur, Okla	293	35	[illegible]	121	[illegible]	[illegible]	[illegible]
19	Lake	Yellowstone Lake, Wyo	20	[illegible]	9		12	[illegible]	[illegible]
20	River	Hot River, Wyo	197	[illegible]	236		50	[illegible]	[illegible]
21	Springs	Livingston, Mont	30	14	168	248	29	222	12
22	do	Denver, Colo	6,525	7,287	302		28	[illegible]	1,192
23	Well	Pueblo, Colo	261	33	[illegible]		10	[illegible]	
			Milligrams per liter	*Milligrams per liter*	*Milligrams per liter*	*Milligrams per liter*	*Milligrams per liter*	*Milligrams per liter*	*Milligrams per liter*
24	do	Coalburg, W. Va	1,750	380	2,220	Trace			[illegible]
25	Brine from oil field	Houston, Tex	31,380	290	2,000			3,510	[illegible]
26	Lake	Lake De Smet, Wyo	1,424	[illegible]	71	67	14	[illegible]	[illegible]
27	River	Bear River, Utah	8	13	43	97	7	[illegible]	[illegible]
28	Spring	Near Ogden, Utah	7,083	93	1,143	[illegible]	[illegible]	218	13,703
29	River	Walker River, Nev	32	1	23	[illegible]	[illegible]	29	13
30	Lake	Lake Tahoe, Calif	11	3	[illegible]	28	[illegible]		[illegible]
31	Spring	Mono, Calif	[illegible]	60	[illegible]	[illegible]		313	227
32	Lake	Albert Lake, Oreg	15,228			6,006	[illegible]	[illegible]	[illegible]
33	do	Soap Lake, Wash	10,504	108	Trace	[illegible]	[illegible]	[illegible]	[illegible]
34	Sea water	Gulf of Mexico, near Tortugas	[illegible]	1,305	112	126		[illegible]	[illegible]

[1] These analyses were made in the laboratory of the U. S. Geological Survey. See Water Supply Paper 364, by F. W. Clarke, 1914.

TABLE 4.—*Water-extracted chemicals from soils*

Soil	Potash and soda	Magnesia	Lime	Phosphoric acid	Silica	Sulphuric acid	Sodium chloride	Carbonic acid
	Parts per million	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*	*Parts per million*
Bonn, Saxony	126	38	128	31	48	100	[illegible]	
Chemnitz, Saxony	38	37	84	Trace	26		48	
Sassafras sandy loam	13	18	74	7	6	54		11
Norfolk, N. C., sandy soil	21	23	58	10	8	43		20
Janesville, Wis., loam	25	52	135	17	40	125		29
Hagerstown, Pa., clay loam	22	77	165	12	21	188		97

The movement of solutions through mortar is disclosed by the formation of crystalline deposits such as are illustrated in the photomicrograph shown in figure 2.

ELECTROLYTIC PROPERTIES OF MINUTE FILMS IMPORTANT IN THE STABILIZATION OF SOIL

The theory of adhesives [12] has much significance in the selection of chemical admixtures for stabilizing soils. For a given cementing material to adhere strongly to a solid surface it must be adsorbed at the solid surface; it must wet the solid surface and form a liquid film there. For an adhesive to wet a soil particle coated with an existing soil gel or in the presence of air, the adhesive must be adsorbed more strongly than either the gel or the air and must displace whichever one is present.

After a period of drought, adsorbed air on the surface of dust particles will often cause raindrops to roll along in the dust without wetting it. Even after a heavy shower the dust may be wetted only to a depth of less than ¼ inch. Any treatment that cuts down the amount of adsorbed air makes the dust more easily wetted. In like manner any treatment that reduces the affinity of the soil particle for the existing film of gel with which it may be covered makes the soil particle easier to coat with the soil-stabilizing adhesive.

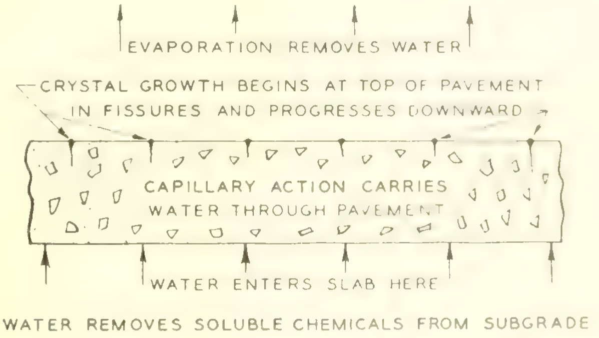
EVAPORATION REMOVES WATER
CRYSTAL GROWTH BEGINS AT TOP OF PAVEMENT IN FISSURES AND PROGRESSES DOWNWARD
CAPILLARY ACTION CARRIES WATER THROUGH PAVEMENT
WATER ENTERS SLAB HERE
WATER REMOVES SOLUBLE CHEMICALS FROM SUBGRADE

FIGURE 1.—ILLUSTRATING GROWTH OF CRYSTALS BY CHEMICALS THROWN OUT OF SOLUTION.

However, materials used to reduce or increase the affinity of soil particles for existing coatings can be selected only after obtaining some knowledge of the electrolytic properties of the soil particles, of the existing films, and of the proposed adhesives.

For a given adhesive and given soil particles, the thinnest film is the strongest. A slight change in either the adhesive or the materials to be cemented is sufficient to cause considerable variation in the thickness of the adhesive film and consequently in the

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[12] See Applied Colloid Chemistry, by Wilder D. Bancroft. McGraw-Hill Book Co., Inc., New York and London, 1932.

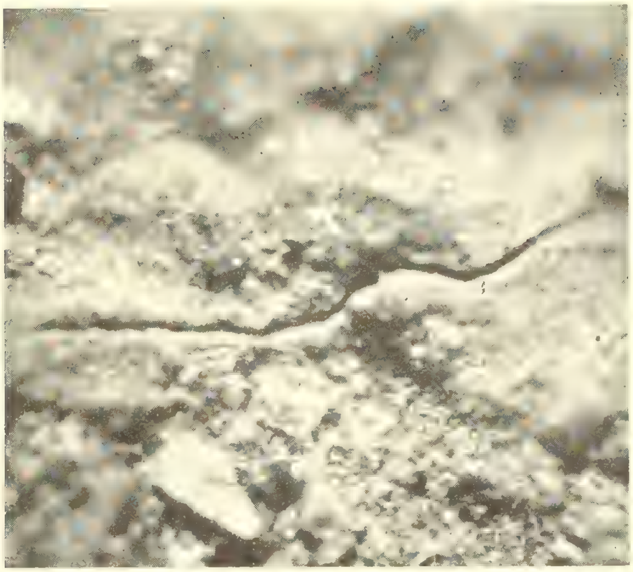


Figure 2.—Deposits of Chemical at Edges of Fissure in Mortar. Length of Fissure Shown About One-Sixteenth Inch. Magnified 55 Diameters.

strength of the resulting mixture of adhesive and aggregate.

A knowledge of the chemical composition of materials serves to throw some light on their electrolytic properties. The chemical composition of the water-soluble constituents of soils controls to some extent the electrolytic properties of the existing gel films. This explains the interest aroused in the study of soil solutions in connection with research on soil stabilization by means of chemicals or admixtures of substances other than soil materials. Such research, however, is just getting under way. To date microchemical analyses have been used principally in studying the durability of concrete and the warping of concrete pavements.

SIMPLE PROCEDURE INVOLVED IN ANALYSIS BY THE MICROCHEMICAL METHOD

Examination has been made of samples of subgrade soil and concrete from numerous locations in the United States, of samples of ground water and solutions of soil chemicals made synthetically, and of cement mortar samples treated specially in the laboratory. The procedures used were essentially as follows:

Soil samples.—Thirty-five grams of soil, air dried and prepared as for routine subgrade tests (see Public Roads, September 1931), were placed with 30 grams of distilled water in a crystallizing dish about 2 inches in diameter and 1¼ inches high and were thoroughly mixed four times by stirring at intervals of 1 hour. The apparatus used is shown in figure 3. One hour after the last mixing the solution portion of the mixture was decanted with a pipette and filtered through high-grade filter paper. Six drops of the filtrate were then placed on a glass slide which was then placed in a desiccator. The slide was examined under the microscope when the liquid had evaporated. Photomicrographs were made of the crystal formations either as nuclei or as a mass.

Cement mortar and scale samples.—Samples of concrete, concrete scale, and the like were pulverized in a mortar with a pestle. Twenty-five grams of the resulting powder and 15 grams of distilled water were then placed in a crystallizing dish. The mixture was stirred and the slides were then prepared in the same manner as was done with the soil samples.

Ground water.—Ground water, sampled full-strength in the field, was filtered in the laboratory in the same manner as the soil and scale solutions. Slides were made from the resulting filtrates in the manner just described for the soil filtrates.

Solutions of known chemicals and synthetic alkalis.—Solutions of known chemicals and synthetic alkalis were filtered and then examined in the same manner as the other filtrates described above.

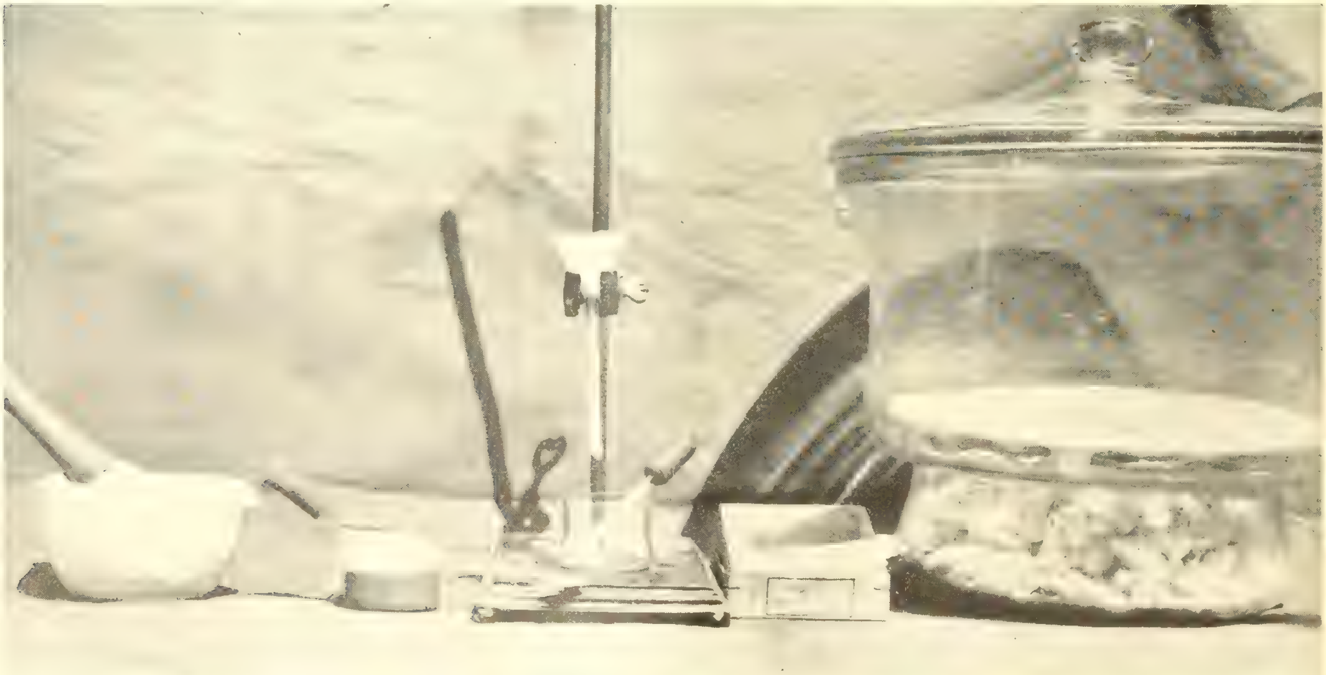
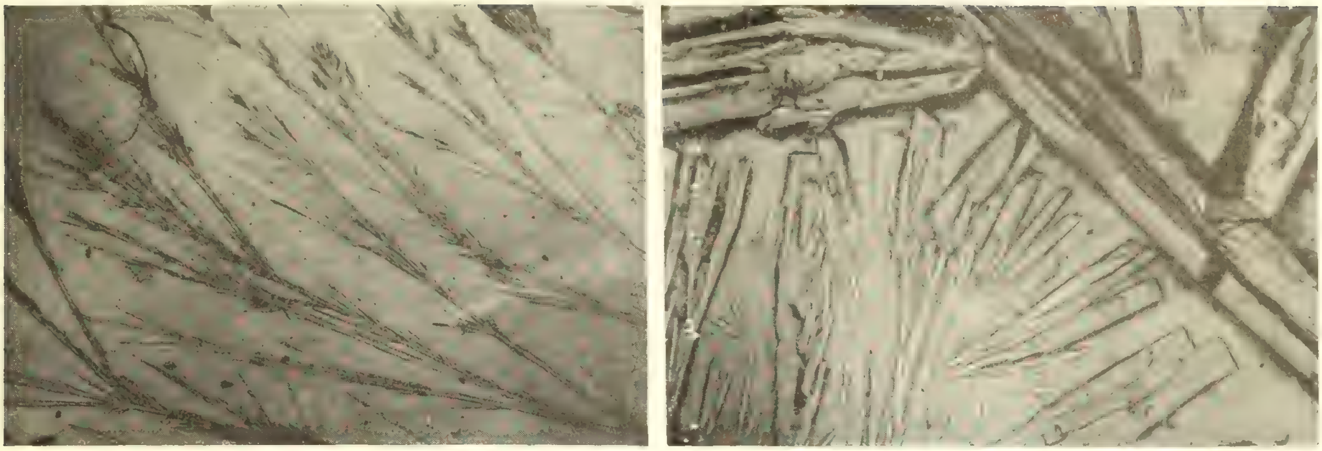
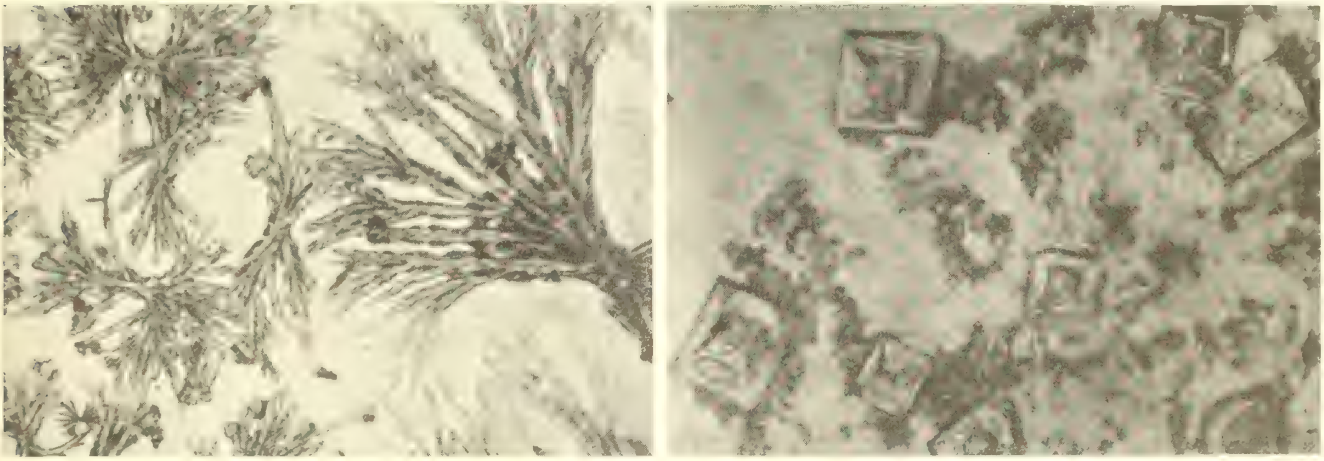


Figure 3.—Apparatus Used in the Preparation of Samples for Microscopic Examination.



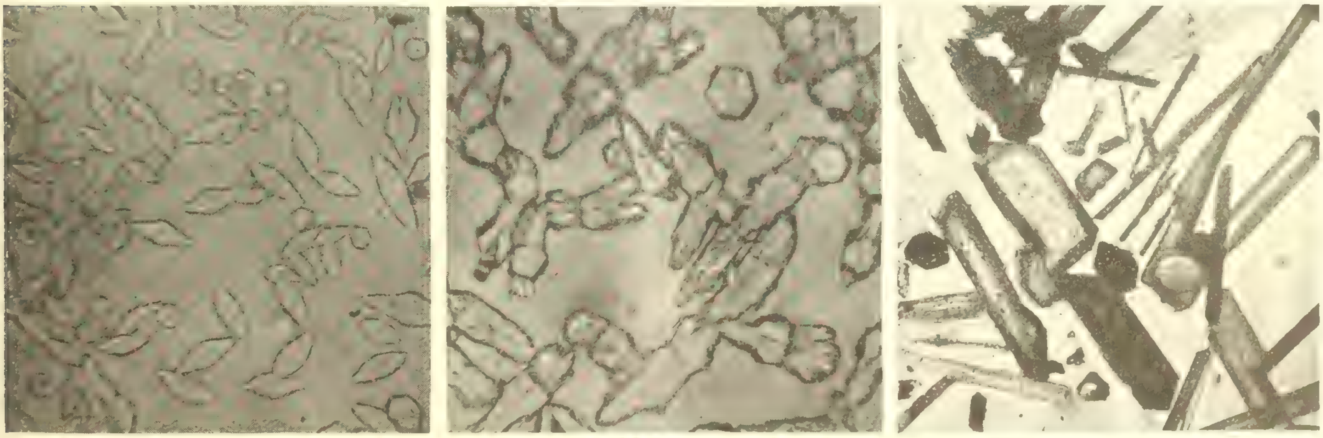
A - DILUTE SODIUM HYDROXIDE
50 D

B - CONCENTRATED SODIUM HYDROXIDE
50 D



C - SODIUM CARBONATE
100 D

D - SODIUM CHLORIDE
100 D



E - DILUTE SODIUM SULPHATE
100 D

F - MODERATE SODIUM SULPHATE
100 D

G - CONCENTRATED SODIUM SULPHATE
64 D

FIGURE 4.—TYPICAL SODIUM CRYSTALS.

TYPICAL CRYSTALS OF WATER-SOLUBLE MATERIALS PHOTOGRAPHED

Figures 4, 5, and 6 show photomicrographs of crystals f the well-known chemicals examined. An attempt vas made to include the constituents of common soils nd chemicals that various authorities believe may ttack concrete.[13] In figure 4 and those that follow the magnification is shown in diameters, the letter "D" being used to indicate diameters.

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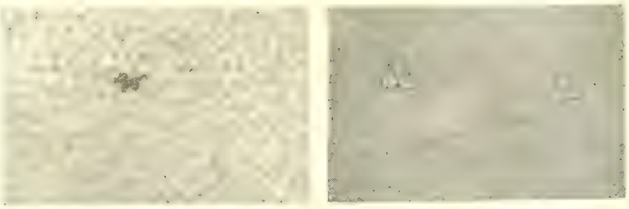
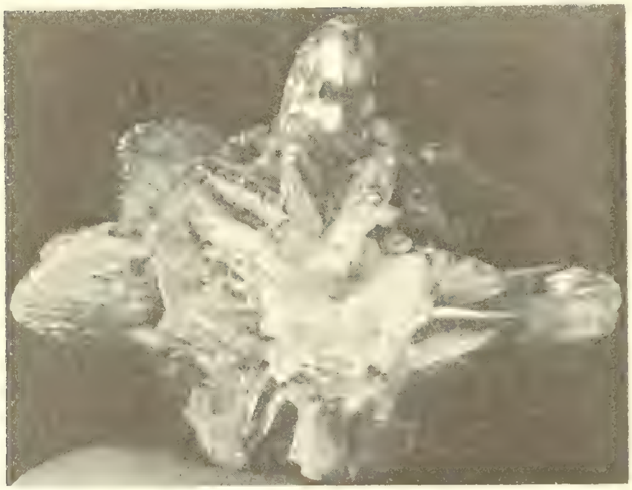
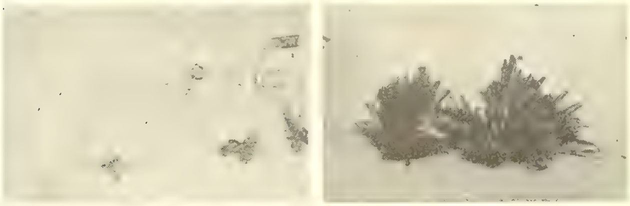
[13] Disintegration of Concrete, report of committee [illegible], Journal A. C. I., vol. 1, no. 1, November 19[illegible]
The Action of Sulphate Water on Concrete, by D. G. Miller, PUBLIC ROADS, vol. 8, no. 9, November 1927.
The Causes of Concrete Destruction [illegible], Proceedings First International Congress [illegible]



A CALCIUM HYDROXIDE 85 D B -CALCIUM CHLORIDE 135 D



C.-CALCIUM SULPHATE CRYSTAL. 1.7 D



D - CALCIUM SULPHATE 45 D E-CALCIUM SULPHATE. 45 D

FIGURE 5. TYPICAL CALCIUM CRYSTALS. D SHOWS CRYSTALS FORMED FROM A WEAK SOLUTION AND E SHOWS CRYSTALS FORMED FROM A STRONG SOLUTION.

Additional information on the appearance of typical crystals is furnished by a number of reproductions of photomicrographs by Arthur W. Doubleday [14] and drawings by Carl G. Hinricks.[15]

Terms such as "strong," "normal," "weak," and "amorphous" were used to designate the degrees of crystal concentration found.

"Strong" signifies a vigorous mass-growth, one crystal occasionally extending throughout the field of vision (figs. 4–B and 5–E).

"Normal" was used to signify definitely formed individual crystals distributed generally throughout the field of vision (figs. 4–D and 6–C).

"Weak" was used to designate crystal nuclei of which a relatively few occurred in the field of vision (figs. 5–B and 6–E).

"Amorphous" was used to designate growths similar in appearance to cement mortar (fig. 6–F).

It is interesting to note how the crystals of some chemicals differ in character due to differences in the strengths of the solutions from which the crystals were obtained. This is true of crystals from sodium hydroxide (figs. 4–A and 4–B), from sodium sulphate (figs. 4–E, 4–F, and 4–G), and from calcium sulphate (figs. 5–D and 5–E). This was not found true for crystals from magnesium sulphate solutions.

The calcium sulphate or gypsum crystal shown in figure 5–C, has a maximum lineal dimension of about 2 inches. It was obtained by W. I. Watkins from the Red River valley in Minnesota. Samples of gumbo soil from this location were examined in connection with studies of the warping of concrete pavements. The alkali crystals (fig. 6–C) were made up synthetically to represent crystals that might be expected to be formed by the water at Billings, Mont. The effect of this water on concrete has been extensively studied.[16] The alkali crystals and those shown in figure 6–E have a typical saw-buck form similar to crystals from dilute sulphate solutions.

The crystals shown in figures 6–F and 6–G are from two samples of the same cement mortar. The sample of figure 6–G was subjected to the action of a synthetic alkali solution while that represented by figure 6–F was not subjected to such action. The mortar furnishing the crystals shown in figure 6–G was obtained from that portion of a test sample located about 2 inches above the portion of the sample in contact with the chemical solution. The treatment had progressed for about 2 months.

The hexagonal crystals from the treated mortar (fig. 6–G) were probably produced by the same sulphates that produced the saw-buck crystal. The hexagonal form of the sulphate crystal has been found only in cement mortars and concretes, and may be due to the presence of sulphur in the mortar as well as in the penetrating chemical solution.

VARIABLES AFFECTING CRYSTAL GROWTH DISCLOSED BY OBSERVATIONS ON MORTAR SAMPLES IN THE LABORATORY

Field inspections of concrete pavements show that crystal growth is quite erratic, occurring at times on one side of the pavement and not on the other, and even in one portion of a slab and not in the remainder. This suggests the possibility that mixing or curing conditions in addition to characteristics of materials may influence crystal growth. Variables that should be investigated are the amount of water used in the mixture, the manner of curing, and the loss of moisture from the slab by evaporation due to temperature and wind and due to absorption by the subgrade soil.

Some information was obtained on this phase of the problem as a result of observations made on three sets of samples subjected to the action of synthetic alkali solutions in the laboratory. The first set consisted of 8 samples, 2 inches in diameter and 1½ inches high made with 1:2 mortar in the spring of 1932. The second set consisted of 8 samples, 4 inches wide, 6 inches long, and ½ inch thick made with 1:1½ mortar at the same time as the first set. The third set consisted of 4 samples, 4 inches in diameter and 4 inches high, made with 1:1½ mortar in the spring of 1933.

All of these samples were placed on porous sand bases saturated with alkali solution. An impervious seal was placed around each sample to prevent the escape of the alkali solution except by capillary action through the sample.

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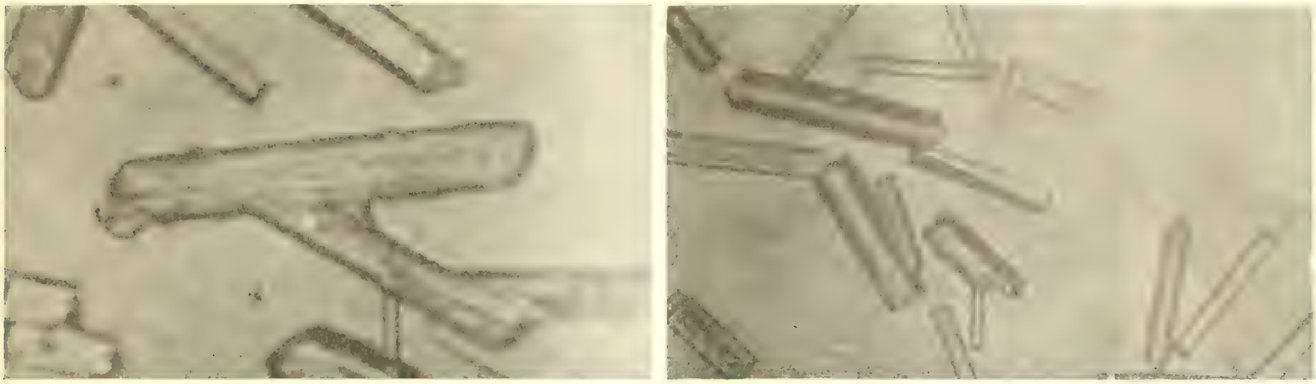
[14] Photomicrographs of Crystals [illegible], by Arthur W. Doubleday, 1916, Research Publishing Co., Boston, Ma

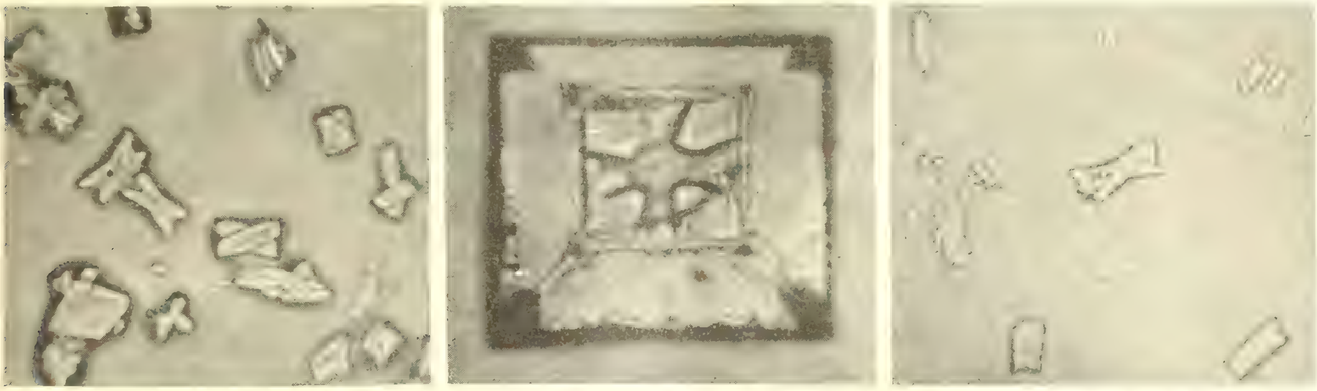
[15] Microchemical Analysis, by Carl G. Hinricks.

[16] Bulletin No. 81 of Montana Agricultural College Experiment Station.



A - MAGNESIUM SULPHATE 275 D

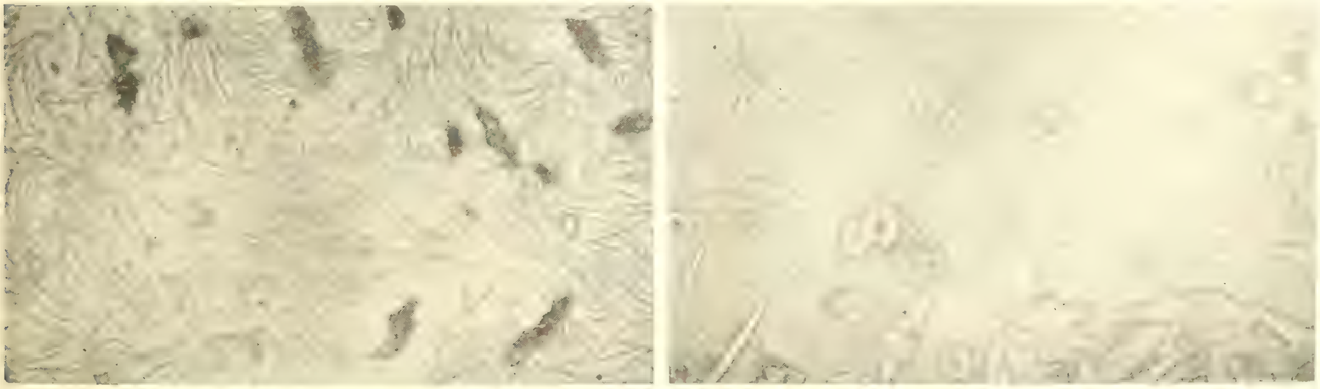
B - POTASSIUM SULPHATE 64 D



C - ALKALI 200 D

D - POTASSIUM IODIDE 200 D

E - CALCIUM CHLORIDE AND MAGNESIUM SULPHATE. 450 D



F - FROM NORMAL CEMENT MORTAR 50 D

G - FROM CEMENT MORTAR AFTER TREATMENT WITH MAGNESIUM AND SODIUM SULPHATES 50 D

Figure 6.—Miscellaneous Crystals.

Observations of these samples definitely disclosed that disintegration is caused by solutions drawn upward by capillary action. The disintegration began at the top of samples and progressed downward. It was also disclosed that the rate at which disintegration occurs, if it occurs at all, is considerably affected by slight changes in materials, in the method of mixing and placing, and in the curing. Figure 7 shows variations in the condition of samples of the first set after subjection to the alkali action for approximately 6 weeks.

In studying the durability of concrete, inspections were made of many concrete pavements and some attention was also given to culverts, retaining walls, piers, abutments, and sidewalls. Aside from pavements in good condition, the examinations were confined to areas with conditions as shown in figure 8.

In general, concrete pavements and adjacent subgrades were sampled in the following manner: A location representative of conditions was selected after careful visual inspection and the soil was sampled through a hole dug in the shoulder adjacent to the pavement as shown in figure 9. The concrete was sampled above the location of the soil sample by means of hammer and drill. Results of the analyses are shown in figures 10 to 18 inclusive.

Figure 11 shows crystals formed from subgrade soli beneath pavements in New York State.

Figure 13 shows a disintegrated concrete gutter, a sealed pavement adjacent to the gutter, a crystal produced from the mortar of the gutter, and a crystal produced from the subgrade soil beneath the gutter.

Figure 14 shows a miscellaneous group of saw-buck crystals formed from subgrade soils beneath pavements that had scaled and crystals formed from concrete surfaces and structures that had deteriorated.

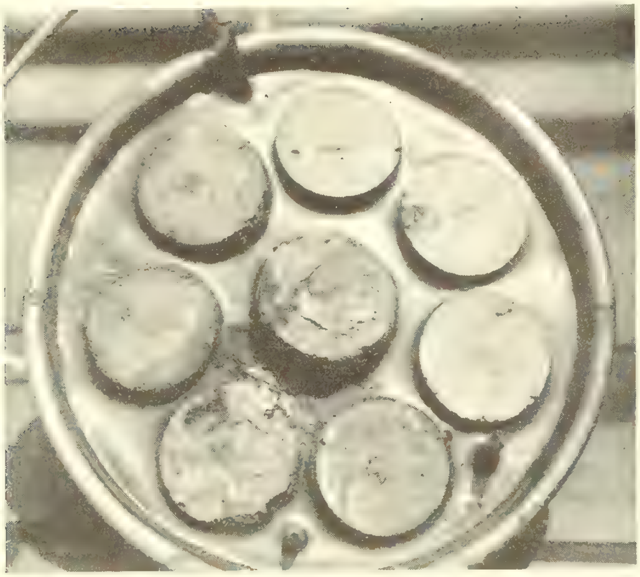


Figure 7.—Cement Mortar Samples Subjected to Sulphate Action.

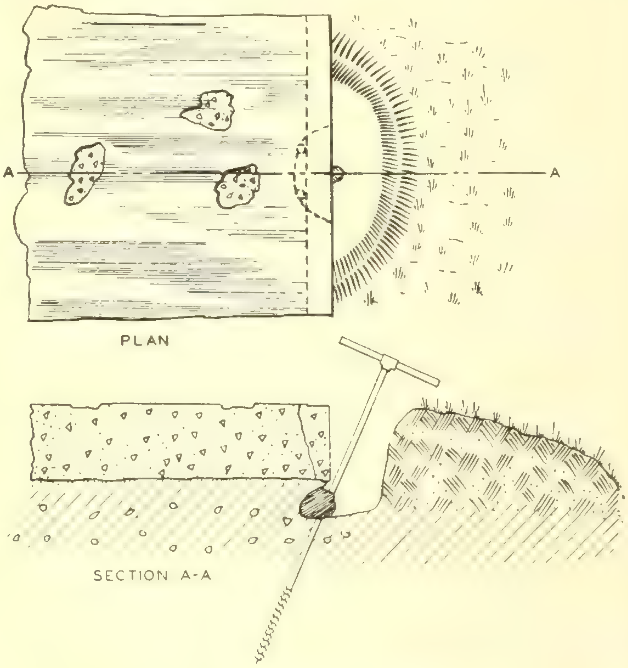
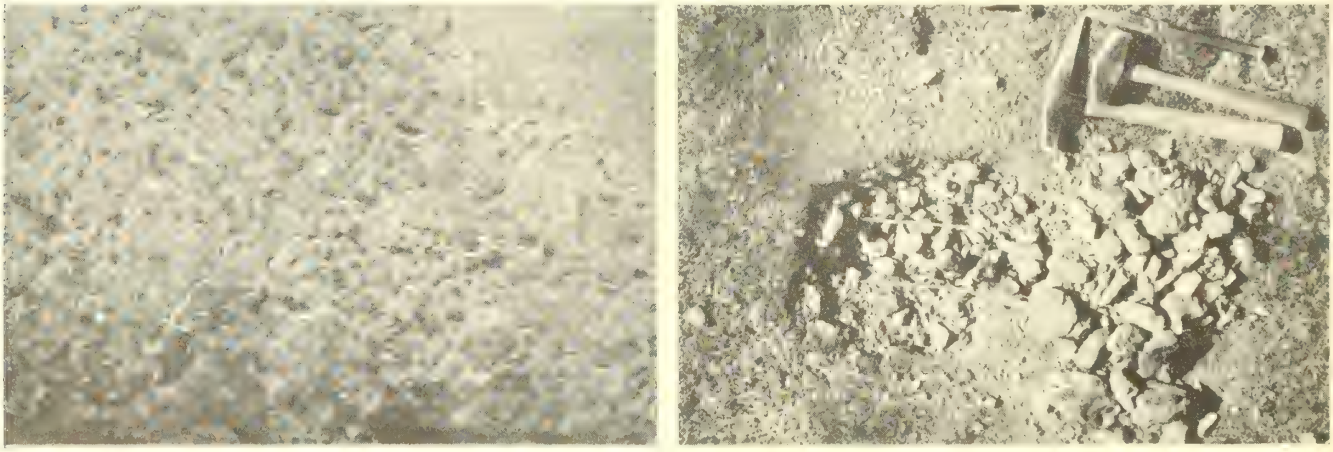
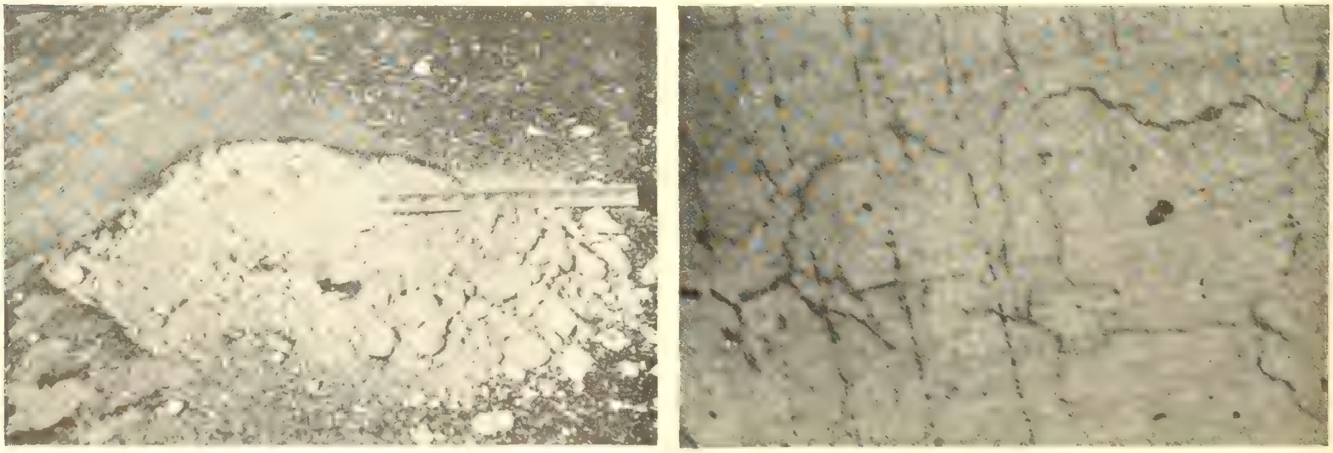


Figure 9.—Method of Sampling.



A - MOTTLED SLAB. SERVICEABILITY NOT REDUCED. AGE 7 YEARS

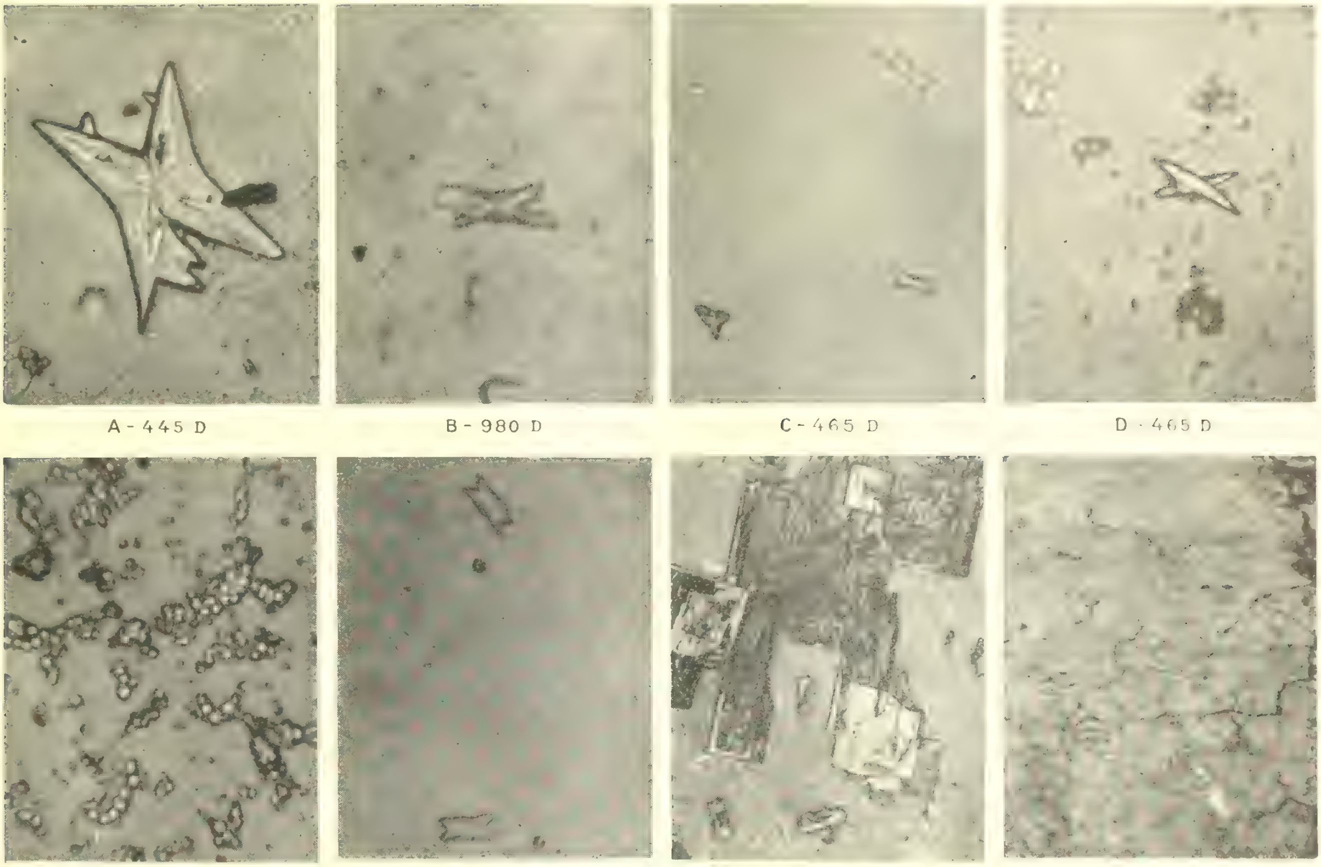
B.- PROGRESSIVE SCALE AGE 9 YEARS



C - CONCRETE POWDERED AND COHESIONLESS. AGE 10 YEARS

D.- MAP CRACKING AGE 4 YEARS

Figure 8.—Types of Pavement Condition Indicative of Crystal Growth.



A - 445 D B - 980 D C - 465 D D - 465 D

E - 465 D F - 205 D G - 65 D H -

FIGURE 10.—CRYSTALS FORMED FROM DETERIORATED STRUCTURES AND THE ADJACENT SOIL AND WATER. A, FROM SOIL UNDER PROGRESSIVELY SCALED SECTION OF ROAD IN VIRGINIA. THE FISSURE SHOWN IN FIGURE 2 WAS IN A SCALED SECTION OF THIS ROAD. B, FROM DISINTEGRATED TILE IN DAMAGED WALL IN BUFFALO, N. Y. C, FROM A BADLY DISINTEGRATED WALL IN PENNSYLVANIA. D, FROM WATER FLOWING OVER SAME WALL AS IN C. E, AMORPHUS CALCIUM CARBONATE FROM SOIL IN PENNSYLVANIA. F, FROM SOIL UNDER FISSURED PAVEMENT SHOWN IN H. G, SALT CRYSTALS FROM CONCRETE IN BADLY CRACKED AND CHECKED ROAD IN ALABAMA. H, FISSURED PAVEMENT IN GEORGIA.

Figure 15 shows crystals produced from a scaled section of concrete slab, and also from the saturated sand cushion, the ground water, and the subgrade soil beneath the slab.

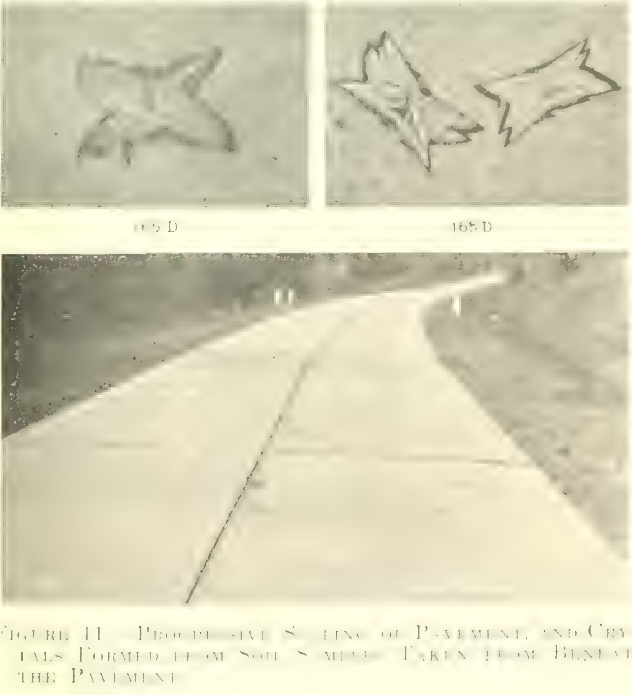
Figure 16 shows damage to new and old sections of a retaining wall and sulphate crystals formed from samples from the new wall and from the soil.

Figure 17 shows the hexagonal form of sulphate crystals made from six samples of mortar from different concrete structures. Five of the six structures showed evidences of scaling. The lower right crystal was made from a sample from the culvert head-wall shown.

The upper pictures of figure 18 show salt crystals formed from deteriorated concrete, probably damaged by ice-prevention measures. The lower pictures of figure 18 show strong sulphate crystals made from spring water from a side-hill cut adjactent to concrete that had disintegrated.

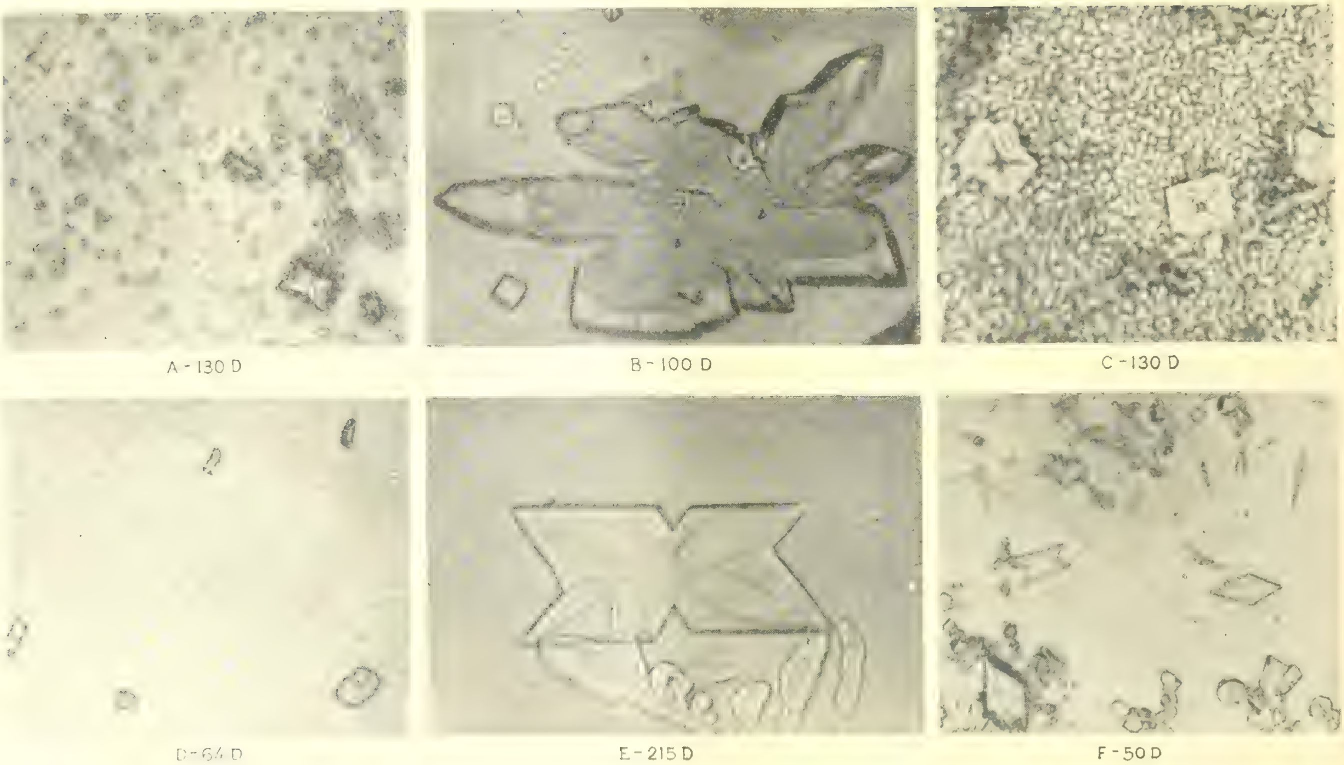
LABORATORY TESTS CONVINCING THAT HARMFUL CHEMICALS ARE DEPOSITED BY CAPILLARY ACTION

The foregoing data have been presented to demonstrate the suitability of the microchemical method of analysis for determining the presence of chemicals in



165 D 165 D

FIGURE 11.—PROGRESSIVE SCALING OF PAVEMENT, AND CRYSTALS FORMED FROM SOIL SAMPLES TAKEN FROM BENEATH THE PAVEMENT



A-130 D B-100 D C-130 D

D-64 D E-215 D F-50 D

Figure 12.—Typical Crystals from Soils and Mortars. A, From Red River Valley Gumbo in Minnesota. B, and C, From Deteriorated Pavement Slab in Alabama. D, From a Texas Soil Associated with Pavement Warping. E and F, From California Soils Associated with Pavement Warping.

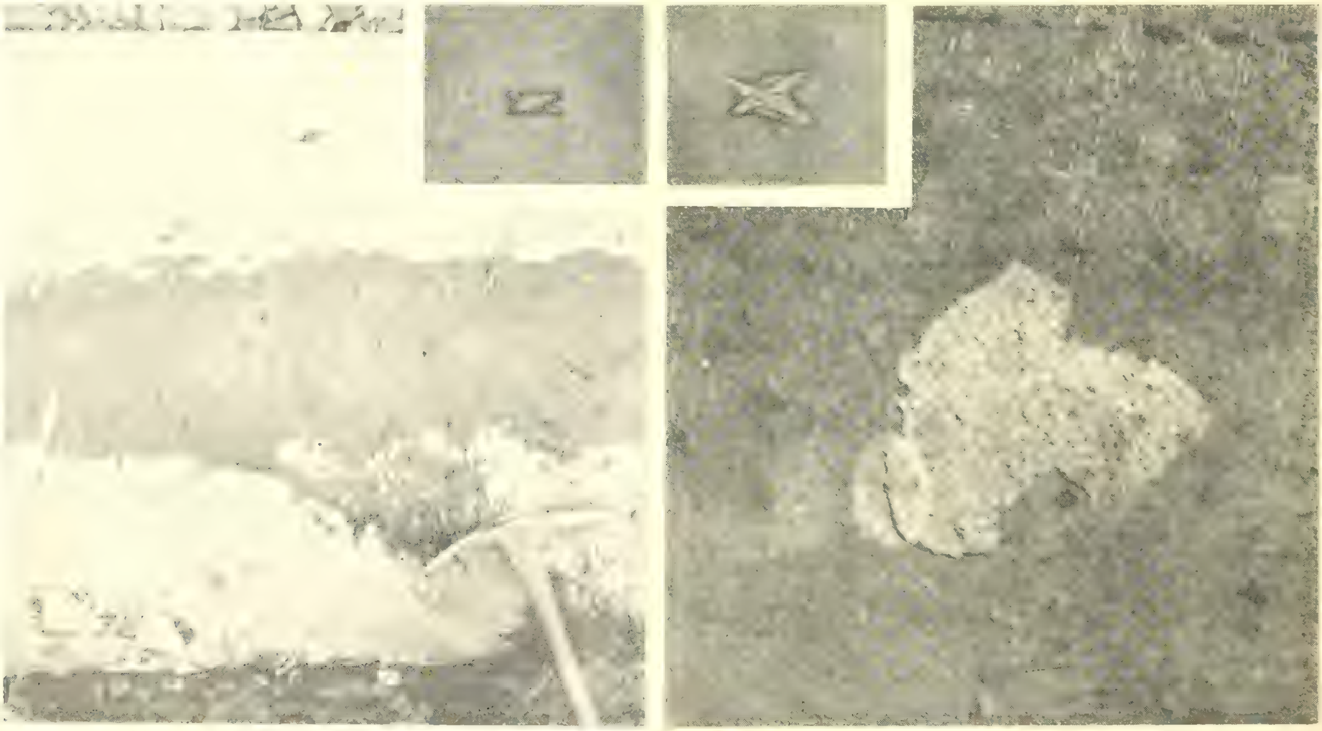
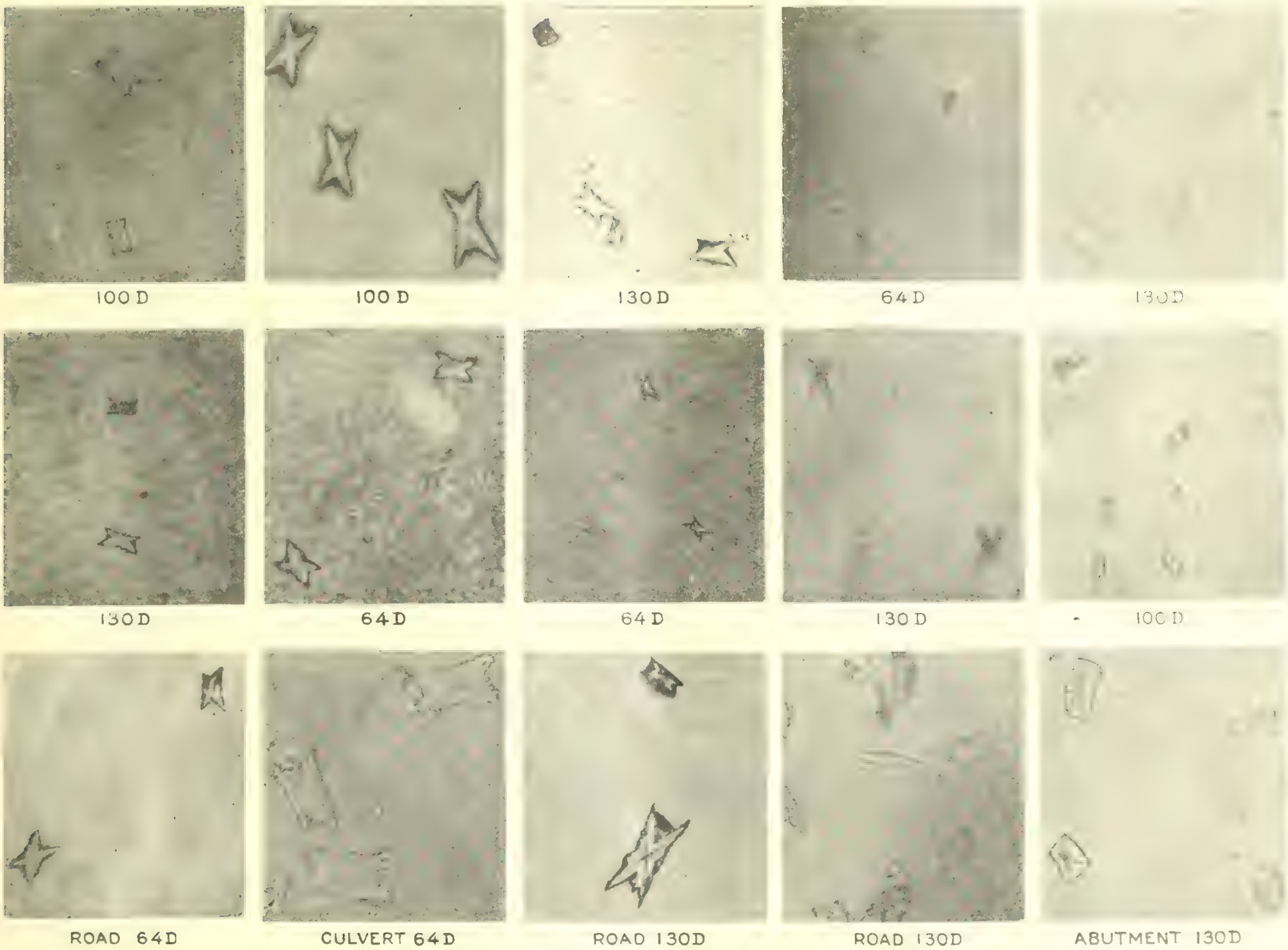


Figure 13.—Scaling of Concrete Gutter and Adjacent Road Surface. The Left Inset Shows a Crystal (220 D) Formed from the Soil Beneath the Gutter, and the Right Inset Shows a Crystal (70 D) Formed from a Sample of Concrete from the Gutter.



100 D 100 D 130 D 64 D 130 D

130 D 64 D 64 D 130 D 100 D

ROAD 64D CULVERT 64D ROAD 130D ROAD 130D ABUTMENT 130D

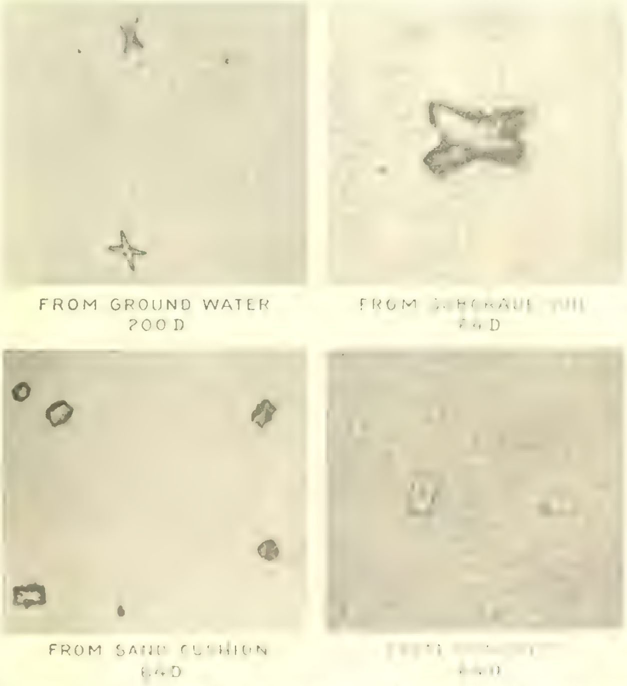
Figure 14. The Two Upper Rows Show Crystals Formed from Soils Beneath Pavements that had Scaled. The Lower Row Shows Similar Crystals Formed from Concrete that had Deteriorated, the Source of Each Crystal Being Indicated.

weak solutions containing soluble constituents of soil, concrete, or other materials.

In studies of soil stabilization it is important that something be known of the character of the films surrounding soil particles. This is indicated by studies made by R. C. Schappler of the Missouri State Highway Department. Referring to clay binders [17] he states that:

> The nature of the ions held on the surface of the colloid, besides affecting the plastic index of the soil, also influences the vapor pressure and the swelling properties of the clay in contact with free water surfaces. The importance of the above facts is apparent since, by taking advantage of the base exchange capacity of the soils available, it is possible in some cases to adjust the properties of soil so as to supply a satisfactory binder. With a given soil it is possible to select a cation for exchange which will result in a small amount of swelling, a relatively large plastic index and a low vapor pressure.

None of our highway surfaces are ideal in composition since they all have voids or interstices filled with unstable materials, air or water being the most common. The distribution of these voids has been shown by Professor Taber's experiments to be of primary importance. A rigid body of porous, homogeneous material will withstand weathering much better than a body having a fissured or laminated composition. The fissured condition produces planes of weakness and the fissures are accentuated by thermal changes, flow of



FROM GROUND WATER 200 D

FROM SUBGRADE SOIL 64 D

FROM SAND CUSHION 64 D

FROM CONCRETE 64 D

Figure 15.— Crystals Made from Materials Taken from the Same Location in a Concrete Road.

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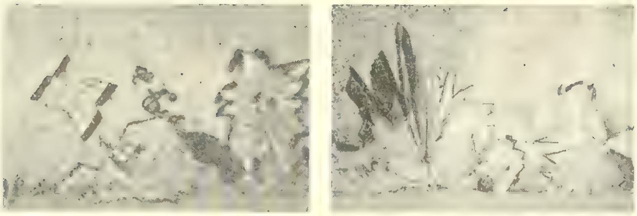
[17] Stabilizing Sand and Gravel Surfaces, by R. C. Schappler, an unpublished paper presented at the Kansas Highway Conference, Manhattan, Kans., Feb. [illegible]



FROM SOIL 125 D FROM CONCRETE 40D

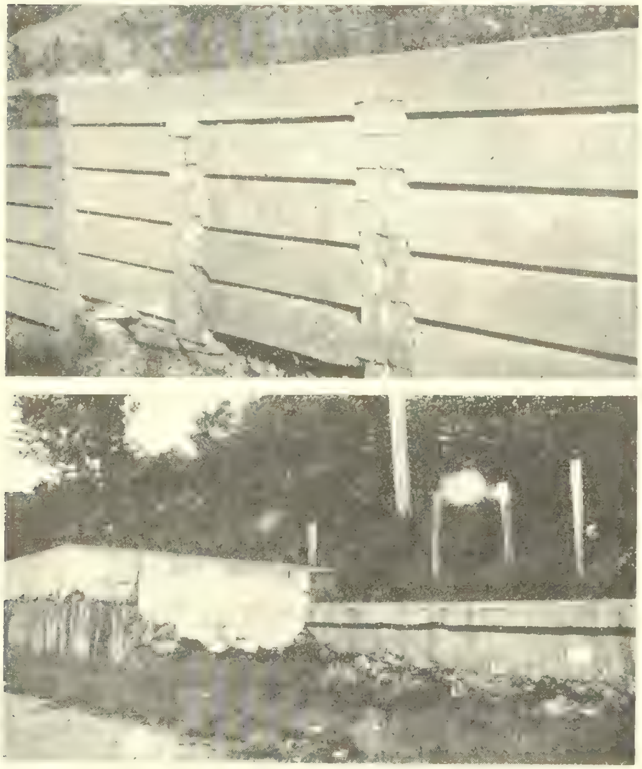
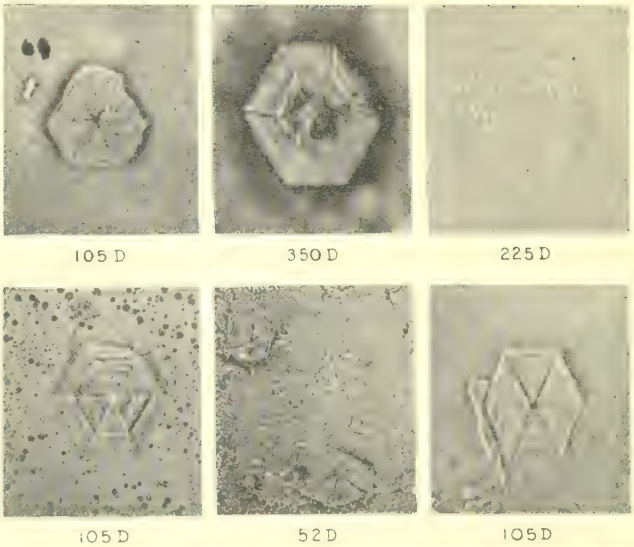


Figure 16.—Disintegrated Retaining Walls and Crystals Formed from the Concrete and Adjacent Soil Indicating Presence of Sulphates.



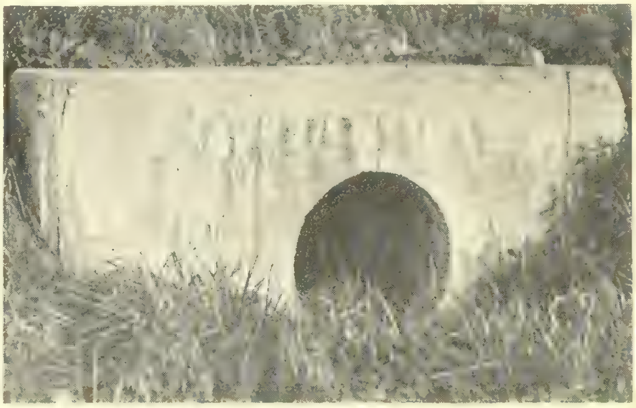


Figure 17.—Six-sided Crystals from Deteriorated Concrete. The Crystals, with the Exception of the One Illustrated on the Lower Right, Were Made from Samples of Road Surfaces. The Lower Right Crystal Was Made from a Sample of the Culvert Head-wall Shown.

moisture, and concentration of deposited material carried in solution or suspension. Fissured surfaces of materials such as rock, wood, and concrete often have a ridge of foreign material along the opening of each fissure.

All natural waters carry some material in solution or suspension, and the logical sources of the material are the soil and the atmosphere. Ground water with concentrations of chemicals as low as seven parts per million of potash and one-half part per million of phosphoric acid will sustain the growth of wheat, corn, or hay. Ground waters and river waters as a rule have much higher concentrations and, in addition to the potash and phosphoric acid, they may contain crystal-forming chlorides, sulphates, and carbonates. A concrete pavement does not have a root system for collecting water from deep in the soil but subgrades often have high capillarity and are capable of continuously supplying moisture to the bottom of the pavement slab. The amount of moisture entering the bottom of the slab and escaping by evaporation from the top depends upon the permeability of the concrete.

Laboratory tests on mortar samples clearly disclosed how solutions in contact with the bottom of the samples were able to pass up through the mortar, deposit crystals, and thus cause deterioration beginning at the tops of the samples. With the crystal growth, there was a horizontal expansion of the mortar amounting to as much as several percent in a month and occurring throughout the height of the sample.

Some samples were able to withstand sulphate action indefinitely without showing any signs of distress. In others resistance to the sulphate action varied greatly depending upon the water-cement ratio used in mixing and also upon the methods of curing.

Table 5 is based on the field studies made and shows that of the 98 samples of mortar from sections of pavement that had scaled, 71 contained soluble chemicals; 78 were from sections constructed on subgrade with poor drainage; 88 were on subgrades with high capillarity; and 65 were on subgrades that furnished crystals, of which 39 were of the saw-buck type.

Of 28 samples of mortar from pavements that had not scaled, but 5 contained soluble chemicals, only one of which furnished crystals of the saw-buck type. Twenty-two samples were from sections laid on poorly drained subgrades, 23 were from sections on subgrades with high capillary properties, and 12 were from sections on subgrades furnishing crystals four of which were of the saw-buck type.

Of 43 samples of mortar from pavements located on subgrade soils yielding the sulphate crystal of saw-buck shape, 39 were from pavements that had scaled.

In some instances, the data may seem to indicate quite positively that a definite relation exists between

TABLE 5.—*Classification of pavement and subgrade samples studied*

Pavement condition	Subgrade soil										[illegible]			
	Drainage conditions			Capillary properties			Crystals of soluble chemicals							
	A Good	B Poor	Ratio A:B	C Low	D High	Ratio C:D	E None	F Sawbuck type	G Other types	Ratio E:F+G	H None	I Sawbuck type	J Other types	Ratio H:I+J
	Number	*Number*		*Number*	*Number*		*Number*	*Number*	*Number*		*Number*	*Number*	*Number*	
Good	6	22	1:3.7	5	23	1:4.6	16	4	8	1:0.8	23	1	4	1:0.2
Sealed	20	78	1:3.9	10	88	1:8.8	33	39	26	1:2.0	27	21	50	[illegible]
Total		126			126			126				126		

the performance of pavements and the occurrence or the character of soluble chemicals in the subgrade soils under the pavements. However, the pavements studied have been subjected to a number of other influences with individual effects that have not been disclosed by the present investigations.

Crystals from the Red River valley gumbo soil on which pavement slabs had warped slightly were similar to gypsum crystals that were found in a Mississippi soil under warped pavement investigated by the bureau.[18] Saw-buck crystals, indicative of the presence of sulphates, were found also in Texas and California soils under slabs that had warped. However, it is not yet definitely known whether the presence of the sulphates was due to a coincidence or if they were factors contributing to the warp.

Until the relative effect of such variables as the drainage and physical characteristics of the subgrade has been determined, data on the association of the water-soluble constituents of the subgrade soil and the occurrence of crystal growth in concrete pavements can be considered of value only as assistance to those interested in making similar research. Information is presented for this reason and not because it is in any way conclusive.

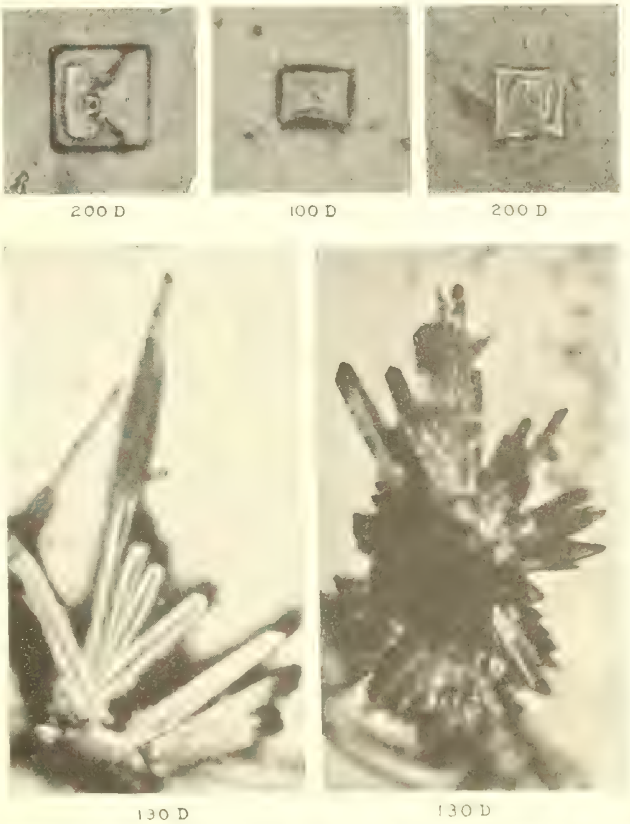


FIGURE 18.—THE UPPER ROW SHOWS SALT CRYSTALS MADE FROM SAMPLES OF CONCRETE. THE LOWER ILLUSTRATIONS SHOW SULPHATE CRYSTALS MADE FROM SPRING WATER.

CONCLUSIONS PRESENTED

Results of investigations seem to indicate that in studies of the factors affecting the performance of concrete surfaces and structures careful consideration should be given to the drainage of the subgrade, the capillarity of the subgrade soil, and the water-soluble constituents in both the concrete and the contiguous soil.

While much yet remains to be learned regarding the microchemical method of analysis, it seems to be especially promising for use as an indicator of the presence of very small amounts of soluble constituents in cements, mortars, road soils, and similar substances.

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[18] See The Soil Profile and the Subgrade Survey by W. I. Watkins and Henry Aaron, PUBLIC ROADS, vol. 12, no. 7, September 1931.

PUBLICATION ON BRIDGE PIERS AVAILABLE

Bridge Piers as Channel Obstructions, by David L. Yarnell, senior drainage engineer of the Bureau of Agricultural Engineering, has recently been published by the Department of Agriculture as Technical Bulletin No. 442.

This bulletin presents the results of numerous experiments on the obstruction of bridge piers to the flow of water. It describes test procedures used and develops coefficients for different shapes of piers using larger piers and a more extensive range of conditions than has hitherto been attempted. The four bridge-pier formulas most commonly used in the United States are discussed.

The bulletin contains numerous illustrations, charts, and applications of the bridge-pier formulas to test and theoretical conditions.

Copies of this publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents each.

STATE MOTOR-VEHICLE REGISTRATIONS, 1934

[Compiled from reports of State authorities]

State	Total motor vehicles	Registered motor vehicles, private and commercial: Passenger motor vehicles: Total	Automobiles (including taxicabs)	Motor busses	Ambulances and hearses	Freight motor vehicles: Total	Motor trucks	Tractor trucks, tractors, etc.	Other registered vehicles: Trailers and semitrailers	Motorcycles	Publicly owned vehicles: Federal: Motor vehicles	Federal: Motorcycles	State, county, and municipal: Motor vehicles	State, county, and municipal: Motorcycles	1933 total registered motor vehicles	Year's change in motor vehicle registration: Increase or decrease	Per cent of change	State
Alabama	225,752	191,651	190,971	211	449	34,101	34,094	7	4,671	620	403	21	831		206,381	19,371	9.4	Alabama
Arizona	96,586	79,795				16,791			2,313	344	672	7	1,525	33	89,496	7,090	7.9	Arizona
Arkansas	198,091	162,391	162,062	329		35,700			7,979	456	297	8	1,172		188,242	9,849	5.2	Arkansas
California	2,006,255	1,768,699				237,556			82,410	8,628	2,502	56	19,663	829	1,971,929	34,326	1.7	California
Colorado	274,231	246,373				27,858			946	826	521	6	[illegible]		266,491	7,740	2.9	Colorado
Connecticut	357,787	301,909	301,002	667	240	55,878	55,818	60	2,570	2,256	733	2	2,856	122	344,731	13,056	3.8	Connecticut
Delaware	54,240	44,846	44,776		70	9,394			1,356	341	149	32	25	96	[illegible]	[illegible]	6.1	Delaware
Florida	335,205	279,846	277,489	502	1,855	55,359			9,886	1,012	596	39	3,902		299,265	35,940	12.0	Florida
Georgia	376,993	312,731				64,262			9,293	990	648	33	[illegible]		330,147	46,846	14.2	Georgia
Idaho	108,863	91,062	90,926	136		17,801			11,753	574	205	1	1,118	12	96,255	12,608	13.1	Idaho
Illinois	1,453,241	1,281,976				171,265			10,729	1,836	1,810	29	7,689	30	[illegible]	[illegible]	[illegible]	Illinois
Indiana	803,241	680,450	679,582	868		122,791	119,405	3,386	54,425	2,791	589	4			[illegible]	[illegible]	[illegible]	Indiana
Iowa	666,140	591,090	590,873	217		75,050			44,477	1,857	124	40	1,146	154	632,292	33,848	5.4	Iowa
Kansas	528,604	453,099	452,855	244		75,505			3,733	706	538	2			517,981	10,623	2.1	Kansas
Kentucky	352,177	294,732	294,268	464		57,445			[illegible]	1,015	466	32	1,684		[illegible]	[illegible]	12.8	Kentucky
Louisiana	244,007	199,228	198,885	343		44,779	41,157	3,622	6,728	731	450	2	1,430	61	232,688	11,319	4.9	Louisiana
Maine	178,995	141,302	141,185	117		37,693			[27] 7,578	1,057	229	7	2,048	62	168,173	10,822	6.4	Maine
Maryland	332,892	285,541	284,638	903		47,351	44,618	733	1,434	1,553	1,[illegible]8	26	2,500		313,274	19,618	6.3	Maryland
Massachusetts	785,392	686,884	682,750	4,134		98,508			752	1,575	1,301	12	[illegible]		789,788	-4,396	-.6	Massachusetts
Michigan	1,148,953	1,025,548		[illegible]		123,405			92,184	3,062	866	1	12,667		1,077,209	71,744	6.7	Michigan
Minnesota	697,672	593,790	593,584	206		103,882	103,499	383	24,707	1,731	641	15	755		679,243	18,429	2.7	Minnesota
Mississippi	174,934	140,819				34,115			707	160	262		(22)		164,688	10,246	6.2	Mississippi.
Missouri	739,813	632,104	631,783	321		107,709			18,024	1,638	842	11	1,961	8	698,362	41,451	5.9	Missouri
Montana	128,336	97,249		(15)		31,087			506	308	631	7	1,340		110,245	18,091	16.4	Montana.
Nebraska	406,632	350,072	349,893	179		56,560			18,640	1,050	278	4	1,816		390,651	15,981	4.1	Nebraska.
Nevada	32,230	25,839	25,755	84		6,391			910	104	146		533	9	28,324	3,906	13.8	Nevada.
New Hampshire	113,134	90,752	90,525	227		22,382	21,674	[20] 708	2,354	1,081	231	53	450	77	107,631	5,503	5.1	New Hampshire.
New Jersey	864,641	741,290	735,725	4,904	661	123,351			3,734	5,262	872	28	8,676	735	845,734	18,907	2.2	New Jersey
New Mexico	82,900	66,788	66,606	182		16,112			918	264	410	2	1,015	15	76,643	6,257	8.2	New Mexico.
New York	2,269,355	1,970,976	1,965,341	5,098	537	298,379			17,417	11,118	3,048	88	21,960	1,009	2,240,757	28,598	1.3	New York
North Carolina	439,351	384,585	384,193	392		54,766			20,649	1,297	563	9	9,787		382,308	57,043	14.9	North Carolina.
North Dakota	156,203	129,888	129,825	63		26,315			263	249	181		462		153,889	2,314	1.5	North Dakota.
Ohio	1,613,265	1,453,420		(15)		159,845			73,787	6,753	1,604	33	11,575	331	1,554,314	58,951	3.8	Ohio.
Oklahoma	477,292	403,364				73,928			5,420	1,023	742		1,369		451,712	25,580	5.7	Oklahoma.
Oregon	274,117	232,706				41,411			[18] 1,276	1,168	538	3	3,539		239,410	34,707	14.5	Oregon
Pennsylvania	1,681,202	1,466,186	1,460,724	5,462		215,016			13,642	10,549	1,816	53	11,190	1,415	1,635,019	46,183	2.8	Pennsylvania.
Rhode Island	142,394	124,062	123,548	514		18,332			147	772	189	6	1,101	95	136,261	6,133	4.5	Rhode Island.
South Carolina	202,834	181,957	181,828	129		20,877			1,919	559	290	22	2,581	141	162,735	40,099	24.6	South Carolina
South Dakota	169,975	146,143	146,071	72		23,832			10,128	352	342		943	8	169,249	726	.4	South Dakota.
Tennessee	336,313	298,558				37,755			2,991	1,188	415	16	5,800		312,180	24,133	7.7	Tennessee.
Texas	1,312,152	1,085,876	1,085,108	768		226,276	226,164	112	36,798	3,467	1,729	61	12,448	319	1,201,762	110,390	9.2	Texas.
Utah	101,926	84,823	84,366	457		17,103			1,359	431	428	17	806		100,362	1,564	1.6	Utah.
Vermont	77,921	69,309	69,223	86		[21] 8,612			964	600	138	14	(12)		73,576	4,345	5.9	Vermont.
Virginia [25]	373,908	316,640	315,940	700		57,268			[26] 2,509	1,785	1,366	45	4,536	175	[11] 347,883	26,025	7.5	Virginia [25]
Washington	422,238	357,917	357,280	637		64,321			5,470	1,569	1,220	19	5,898	196	427,406	5,168	−1.2	Washington.
West Virginia	194,231	166,978	166,527	451		27,253	26,682	571	1,084	865	162		(9)		226,985	32,754		West Virginia
Wisconsin	709,359	589,179	588,733	446		120,180			8,466	2,476	514		6,309	286	670,797	38,562	5.7	Wisconsin.
Wyoming	64,990	51,888	51,660	228		13,102			5,398	177	332	10	521		52,560	12,430	23.6	Wyoming
District of Columbia	163,070	145,807	145,065	742		17,263			1,169	696	1,854	101	954	67	149,790	13,280	8.9	District of Columbia.
Detailed totals [28]			14,143,565	31,453	3,812		673,111	9,582										Detailed totals.
Grand total	24,933,403	21,524,068				3,409,335			615,315	93,492	36,475	965	193,911	6,299	23,843,591	1,089,812	4.6	Grand total.

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[1] Wherever possible, reregistrations, nonresident registrations, publicly-owned vehicles, and vehicles not for highway use (farm tractors, etc.) have been eliminated from these columns.

[2] As reported by the Budget Bureau in 1931. Total includes 333 motor vehicles "at large" not assignable to any State.

[3] Figures on publicly-owned vehicles are incomplete as State records on this subject are meager in many cases. Some States give State-owned vehicles only; others exclude certain classes, such as fire apparatus and police vehicles, from registration. Publicly-owned vehicles in Maryland and Michigan were given as a total but were not deducted by types from the private and commercial registrations.

[4] A complete segregation of motor busses from other vehicles is not available. The figures given below represent common-carrier busses in most cases, although in some States contract busses and contract school busses are included. In a number of cases city busses are not included, rural and interurban carriers only being given. Where no busses are tabulated, the busses are included in the total passenger registrations, except as noted otherwise.

[5] Ambulances and hearses are reported separately in only a few States, being included with passenger vehicles in some States and with freight vehicles in others.

[6] Included in total freight motor vehicles except where tabulated separately.

[7] For registration year ended Sept. 30, 1934.

[8] Includes 15,139 registrations issued without charge to public service corporations, which pay a gross receipts tax. All common carriers, both passenger and freight, are included with these vehicles.

[9] Common-carrier busses with passenger registrations, contract carriers with trucks.

[10] Includes 25,134 contract carriers, both freight and passenger, common carriers included in passenger registrations.

[11] Revised figure.

[12] Included in private and commercial registrations.

[13] Included with freight motor vehicles.

[14] Not reported.

[15] Includes 41,150 light trailers licensed without charge.

[16] Includes unknown number of Federal vehicles.

[17] Trailers prohibited on highways although permitted in cities under city license, tractor semitrailers registered as trucks. Passenger-car trailers and those of less than 1,600 pounds capacity are permitted but not registered.

[18] Light trailers only; heavy trailers with freight motor vehicles.

[19] Registration required every 3 years, these are 1934 registrations only.

[20] Includes unknown number of agricultural tractors.

[21] Date of ending registration year changed in 1933 from June 30 to Dec. 31. Registrations from July 1 to Dec. 31, 1933, as follows: Passenger motor vehicles, 208,166; freight vehicles, including trailers and semitrailers, 56,187; motorcycles, 1,133.

[22] For registration year ended Oct. 31, 1934. The 1933 registration was for 10-month period.

[23] For 15-month period ended Mar. 31, 1935. Date of ending registration year changed from Dec. 31.

[24] Light delivery trucks with passenger cars.

[25] For registration year ended Mar. 31, 1935.

[26] Contract and common-carrier trailers included with freight motor vehicles.

[27] For 6-month period ended June 30, 1934. Date of ending registration year changed from Dec. 31.

[28] Totals of columns for which figures were obtained from only part of the States. Only the grand totals (line below) give full national figures.

STATE MOTOR-VEHICLE RECEIPTS, 1934

[Includes registration fees, miscellaneous receipts of motor-vehicle departments, and special taxes imposed on motor carriers]

[Compiled from reports of State authorities]

State	Total receipts, registration and other fees [1]	Motor-vehicle registration fees: Total motor-vehicle registration fees [2]	Passenger motor vehicles: Total	Passenger motor vehicles: Automobiles (including taxicabs)	Passenger motor vehicles: Motor busses [3]	Passenger motor vehicles: Ambulances and hearses [4]	Freight motor vehicles: Total	Freight motor vehicles: Motor trucks	Freight motor vehicles: Tractor trucks, tractors, etc. [5]	Registration fees, other vehicles: Trailers and semitrailers	Registration fees, other vehicles: Motor cycles	Total registration fees, all vehicles	Miscellaneous receipts: Total	Miscellaneous receipts: Dealers' licenses and plates	Miscellaneous receipts: Operators' and chauffeurs' permits	Miscellaneous receipts: Certificates of title	Miscellaneous receipts: Fines and penalties	Miscellaneous receipts: Transfer fees and other miscellaneous	Special taxes paid by motor carriers [6]	Grand total, all motor-vehicle fees and taxes [7]	State
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	
Alabama [5]	3,188	[4] 3,183										3,183	5	2				3	63	3,251	Alabama [5]
Arizona	759	600	300				300			28	1	629	130	3	15	50	1	61	105	864	Arizona
Arkansas	2,184	1,972	1,353	1,312	41		619			158	1	2,151	53	17	22		8	6	19	2,203	Arkansas
California	10,140	8,431	[8] 5,846		(9)		[10] 2,585			426	25	8,882	1,258	34	155		66	1,003	1,377	11,517	California
Colorado	2,172	1,632	1,253				379			18	1	1,651	521	19	25	121		[11] 356	186	2,358	Colorado
Connecticut	7,948	6,292	4,759	4,613	140	6	1,533	1,531	2	45	9	6,346	1,602	72	1,293		142	95	151	8,099	Connecticut
Delaware	883	715	490	489	(13)	1	225			13	1	729	154	5	110	27		12	(14)	883	Delaware
Florida	4,409	4,091	2,910	2,785	83	42	1,181			97	5	4,193	216	17	6	149		44	(15)	4,409	Florida
Georgia	1,193	1,129	949				180			27	3	1,159	34	6	14			14	(14)	1,193	Georgia
Idaho	1,560	1,514	1,102	1,095	7		412			17	2	1,533	27	19	2			6	41	1,601	Idaho
Illinois	18,278	16,359	12,388		(13)		3,971			97	16	16,472	1,806	79	237	930		560	6	18,284	Illinois
Indiana	7,260	5,986	4,463	4,384	79		1,523	1,445	78	186	5	6,177	1,083	39	466	224		[16] 354	25	7,285	Indiana.
Iowa	10,034	9,677	7,625				2,052			52	6	9,735	299	46	36		1	216	376	10,410	Iowa.
Kansas	3,278	3,130	2,438		(13)		692			42	3	3,175	103	20	25			58	629	3,907	Kansas.
Kentucky	3,013	2,875	1,967	1,917	50		908			(17)	2	2,877	136	22	18			96	204	3,217	Kentucky.
Louisiana	4,380	4,010	3,026	2,988	38		984	936	48	283	5	4,298	82	13	62		8	[18] −1	(15)	4,380	Louisiana.
Maine	3,165	2,474	1,674	1,663	11		800			[19] 8	6	2,488	677	32	482		12	151	(14)	3,165	Maine.
Maryland	3,523	2,807	2,269	2,151	118		538	521	17	69	7	2,883	640	32	245	144	179	40	(20)	3,523	Maryland.
Massachusetts	6,634	3,791	2,551	2,454	97		1,240			27	2	3,820	2,814	62	2,107		431	214	(14)	6,634	Massachusetts.
Michigan	15,901	13,588	9,494		(13)		4,094			607	11	14,206	1,695	58	785	531		321	297	16,198	Michigan.
Minnesota	6,867	6,409	4,677	4,592	85		1,732	1,722	10	172	6	6,587	280	29	252		2	[18] −3	17	6,884	Minnesota.
Mississippi	1,950	[2] 1,926										1,926	24	2			20	2	73	2,023	Mississippi.
Missouri	7,344	6,562	5,555		(13)		1,007			56	8	6,626	718	64	128	300		226	326	7,670	Missouri.
Montana	1,071	1,006	789		(13)		217			(15)	(15)	1,006	65	15	1	20		29	11	1,082	Montana.
Nebraska	1,945	1,752	1,145	1,131	14		607			26	2	1,780	165	11	65			89	(14)	1,945	Nebraska.
Nevada	248	233	129		(21)		104			4	1	238	10	2				8	139	387	Nevada.
New Hampshire	2,477	[2] 2,035									6	2,041	436	22	316		77	21	5	2,482	New Hampshire.
New Jersey	15,614	11,179	7,800	7,502	281	17	3,379			138	10	11,327	4,287	59	3,296	366	91	475	73	15,687	New Jersey.
New Mexico	843	806	532	511	21		274			8	1	815	28	6			1	21	67	910	New Mexico.
New York	41,664	36,891	26,818				10,073			301	49	37,241	4,423	176	2,993			1,254	(14)	41,664	New York.
North Carolina	6,944	6,793	5,327	5,298	29		1,466			(22)	5	6,798	146			139		7	126	7,070	NorthCarolina.
North Dakota	1,291	1,233	942	936	6		291			3	1	1,237	54	11		17		26	15	1,306	North Dakota.
Ohio	19,961	18,322	12,011		(13)		6,311			609	27	18,958	1,003	92	191			720	(15)	19,961	Ohio.
Oklahoma	3,251	2,724	1,859				865			87	4	2,815	436	32		209		195	610	3,861	Oklahoma.
Oregon [23]	1,843 2,219	1,564 1,986	1,056 1,195				508 791			(22) [19] 6	4 5	1,568 1,997	275 222	10 15	200 70	53 107		12 30	227 620	2,070 2,839	Oregon.[23]
Pennsylvania	30,842	22,658	15,644	15,120	524		7,014			185	29	22,872	7,970	301	4,610	1,337	383	1,339	(15)	30,842	Pennsylvania.
Rhode Island	2,315	1,879	1,428	1,379	49		451			2	3	1,884	431	15	354			62	(14)	2,315	Rhode Island.
South Carolina [24]	2,831	2,510	2,062				448			50	2	2,562	269	13	150		41	65	81	2,912	South Carolina [24]
South Dakota	1,314	1,267	1,110	1,108	2		157			13	(25)	1,280	34	10		19		5	264	1,578	South Dakota.
Tennessee	3,322	[2] 3,292										3,292	30	8			19	3	37	3,359	Tennessee.
Texas [26]	14,921	14,106	9,663	9,566	97		1,443	1,440	3	309	15	14,430	491	38	152			301	48	14,969	Texas.[26]
Utah	966	850	584	575	9		266			13	1	864	102	9	43	31	2	17	218	1,184	Utah.
Vermont	2,157	1,849	1,365	1,352	13		[27] 484			4	4	1,857	300	24	237			39	(14)	2,157	Vermont.
Virginia [28]	4,947	4,289	3,184	3,125	59		1,105			[29] 27	5	4,321	626	42	262	192		130	116	5,063	Virginia.[28]
Washington	2,727	2,296	1,139	1,082	57		1,157			90	4	2,390	337	8	180	138		11	186	2,913	Washington.
West Virginia [30]	1,987	1,766	1,421	1,412	9		345	344	1	11	2	1,779	208	15	100	63		30	30	2,017	West Virginia. [30]
Wisconsin	10,051	9,743	7,340	7,144	196		2,403			173	12	9,928	123	23	18			82	1,034	11,085	Wisconsin.
Wyoming	437	411	275	270	5		136			16	(31)	427	10	5				5	46	483	Wyoming.
District of Columbia	677	169	146	145	1		23			1	1	171	506	3	192	79	203	29	153	830	District of Columbia.
Detailed totals [32]			182,053	88,099	2,121	66	70,273	10,939	159	4,504	318										Detailed totals.[32]
Grand totals	304,928	262,762										267,584	37,344	1,657	19.915	5,246	1,687	8,839	8,001	312,929	Grand totals.

of registration fees by type of vehicle was available in Alabama, Mississippi, New Hampshire, and Tennessee. In these cases the total motor vehicle registration fees include those of trailers and motorcycles, except in the case of New Hampshire, for which the motorcycle fees are given.

[3] The figures for registration fees of busses are incomplete (see preceding table, note 4). Where no fees are tabulated the fees of busses are included in the total passenger registration fees, except as otherwise noted.

[4] Only a few States reported ambulances and hearses separately (see preceding table, note 5). In New York 537 ambulances were reported, but were exempted from payment of registration fees.

[5] Included in total for freight motor vehicles, except where tabulated separately.

[6] Special taxes, such as mileage, ton-mile, and passenger-mile taxes, gross receipts taxes, franchise fees, and special license fees imposed on motor vehicles operated for hire and other motor carriers. Gross receipts taxes paid by common carriers in California and passenger-mile taxes paid by interurban common carrier busses in Maryland are included with registration fees and omitted from this column, as these taxes were paid in lieu of registration fees.

[7] Total including special taxes paid by motor carriers.

[8] For registration year ended Sept. 30, 1934.

[9] Includes gross receipts taxes of $570,000 paid in lieu of registration fees by common carriers, both freight and passenger.

[10] Gross receipts taxes paid by common carrier busses included with passenger vehicle fees; registration fees paid by contract carriers of passengers included with freight vehicle fees.

[11] Includes registration fees paid by contract carriers of passengers; gross receipts taxes paid by common freight carriers included with passenger vehicle fees.

[12] Includes $[illegible]05,000 paid in $1 assessments on motor vehicle registrations for old age pension fund.

[13] Included with fees of freight motor vehicles.

[14] No special taxes on motor carriers.

[15] Not reported.

[16] Includes $180,000 in service charges on registrations in branch offices, not segregated by type of vehicle.

[17] Commercial full trailers prohibited; light trailers not registered, semitrailer units registered as trucks.

[18] Negative item due to deduction of refunds from miscellaneous receipts.

[19] Fees of light trailers only, fees of heavy trailers with those of freight motor vehicles.

[20] Passenger-mile taxes paid by interurban common carrier busses included with registration fees of passenger motor vehicles.

[21] Bus fees $420.

[22] Included with fees of freight motor vehicles.

[23] Date of ending registration year changed in 1933 from June 30 to Dec. 31. Upper line gives figures for 6-month period.

[24] For registration year ended Oct. 31, 1934.

[25] Motorcycle fees $399.

[26] For 15-month period ended Mar. 31, 1935. Date of ending registration year changed from Dec. 31.

[27] Fees of light delivery trucks with those of passenger cars.

[28] For registration year ended Mar. 31, 1935.

[29] Fees of contract and common carrier trailers included with those of freight motor vehicles.

[30] For 6-month period ended June 30, 1934. Date of ending registration year changed from Dec. 31.

[31] Motorcycle fees $396.

[32] Totals of columns for which figures were obtained from only part of the States. Only the grand totals (line below) give full national figures.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JUNE 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 6,241,479	$ 3,370,574	$ 35,889	340.2	$ 2,164,640	$ 530,262	$ 1,235,513	124.0	$ 37,466	$ 459,429	15.5	$ 9,452	$ 399,089
Arizona	3,855,555	1,338,712	4,973,171	3,832,517	458,905	352.6	982,994		870,052	42.4				23,038	9,756
Arkansas	3,734,167	1,714,000	3,407,901	2,517,988	335,091	165.1	1,903,327	643,216	973,715	90.0	158,919	138,897	9.8	14,044	266,297
California	7,912,928	3,713,643	10,979,471	7,752,828	476,000	364.1	3,187,701	158,741	2,119,795	61.1		826,273	21.3	1,360	291,575
Colorado	3,437,265	2,424,504	5,110,152	3,347,941	1,628,991	242.9	957,977	82,697	786,222	44.5	6,627		5.5		9,291
Connecticut	1,404,213	607,500	794,426	791,923		14.5	1,473,554	611,294	554,726	23.4				996	52,774
Delaware	877,566	461,697	1,205,831	868,470	317,537	45.6	138,523	4,973	133,550	3.2	4,082	7,442		40	3,169
Florida	2,469,370	1,116,600	3,289,674	2,214,247	264,420	125.6	864,776	220,895	606,335	30.2		214,470	1.7	34,228	31,375
Georgia	5,045,592	2,556,745	4,583,226	3,921,288	424,651	319.0	2,210,774	978,717	1,149,033	105.1	6,394	240,661	4.6	139,193	742,400
Idaho	2,166,858	1,131,910	2,253,186	2,027,114	154,028	198.5	603,339	131,759	445,173	33.3		283,676	13.7	7,386	249,033
Illinois	4,408,827	2,408,778	2,581,258	2,392,590	142,890	40.3	3,990,572	2,002,682	1,987,890	67.1	3,000	277,998	.4	10,555	
Indiana	5,018,921	2,816,687	3,609,966	3,451,916	35,317	112.9	3,872,034	1,427,908	2,279,625	163.3	77,951	383,180	21.8	61,146	118,564
Iowa	5,027,830	2,217,361	5,139,249	4,720,930	314,620	317.3	2,330,010	306,900	1,715,529	118.1		56,500	4.0		130,712
Kansas	5,044,802	2,354,131	5,916,637	5,004,394	780,019	637.4	1,646,247	31,530	1,546,923	125.2		27,189	1.3	8,878	
Kentucky	3,751,605	1,302,209	3,821,618	3,379,305	196,985	280.5	1,193,398	316,514	792,539	56.7		234,307	11.2	55,786	78,378
Louisiana	2,693,135	1,380,419	2,705,069	2,295,365	40,687	76.8	1,620,868	368,904	1,098,700	28.9	11,070	1,326	.2	17,795	239,706
Maine	1,567,012	782,195	1,557,493	1,433,664	93,720	47.4	612,469	117,934	494,535	10.1		192,289	6.8	15,415	1,652
Maryland	1,782,263	289,609	867,379	791,495	74,649	15.5	975,603	797,232	178,571	21.3	106,646		1.1	86,889	36,389
Massachusetts	1,101,716	1,582,874	1,466,324	1,049,029		37.4	1,094,397	52,687	989,888	20.2		5,351			587,635
Michigan	6,051,533	3,226,284	5,256,446	4,921,541	81,400	234.2	3,447,600	1,075,800	2,351,441	135.8		579,025	26.6	54,191	214,417
Minnesota	4,561,011	2,533,733	5,781,092	4,235,784	1,365,525	910.1	929,965	192,248	737,117	119.9	50,482	284,629	41.8	82,498	146,462
Mississippi	3,489,337	2,832,182	5,139,817	2,521,709	490,683	269.2	2,870,880	893,810	1,323,253	160.1	5,574	684,578	34.6	68,244	333,666
Missouri	5,237,532	2,890,666	4,883,071	4,295,899		198.1	2,917,170	861,589	1,877,066	84.8		1,013,600	41.0	80,044	
Montana	4,463,849	2,714,208	6,439,794	4,403,621	1,566,281	564.4	1,081,902	4,129	975,696	71.6		129,645	.2	56,099	42,586
Nebraska	3,914,481	1,982,182	5,153,191	3,888,842	137,284	369.4	2,124,944	25,639	1,748,712	105.0		40,817	.4		55,369
Nevada	2,909,387	1,350,356	3,360,319	2,683,175	604,881	322.5	687,097	187,644	498,786	99.7	34,908	234,342	60.3	3,660	12,347
New Hampshire	692,118	465,404	728,305	612,389	89,273	12.6	453,251	79,729	352,131	10.7					24,000
New Jersey	3,173,019	951,379	2,231,743	2,025,846	15,000	37.4	1,786,167	1,113,074	575,607	15.2		10,167		34,100	350,605
New Mexico	2,846,648	1,676,769	3,704,872	2,748,086	812,459	363.9	677,033	98,562	562,946	45.0		301,364	18.6		
New York	10,465,672	3,748,600	11,541,859	9,011,288	230,230	224.0	7,545,310	1,262,472	3,246,552	137.4		26,900		191,912	244,918
North Carolina	4,761,147	1,930,365	4,954,230	3,616,813	390,706	602.7	1,506,646	786,550	528,689	156.7	64,450	367,269	19.0	293,334	643,701
North Dakota	2,902,224	1,469,484	3,257,884	2,602,966	217,676	1,122.4	682,417	97,071	409,315	203.6	148,356	255,096	157.6	53,830	587,396
Ohio	7,277,758	3,539,255	7,519,150	7,040,235	88,100	195.2	3,374,726	186,081	2,854,513	69.1	42,800	3,420	.8	8,642	593,223
Oklahoma	4,608,399	2,342,590	4,722,067	4,201,027	384,143	318.1	2,037,234	396,183	1,428,537	79.9	10,819	367,151	11.2	369	162,759
Oregon	3,053,448	1,452,741	3,615,203	2,942,973	279,947	193.9	1,304,366	80,590	1,103,852	55.4				29,885	68,942
Pennsylvania	6,691,194	4,554,082	7,057,671	6,190,605	593,079	139.9	4,430,735	442,031	3,757,564	81.1	2,126	6,816		56,432	196,623
Rhode Island	979,367	474,772	968,005	899,627		20.5	560,592	79,740	464,572	14.3					10,200
South Carolina	2,729,583	940,954	2,536,142	2,359,621	111,965	217.0	667,046	315,630	351,416	55.7	18,520	27,220	.3	35,811	450,354
South Dakota	3,005,739	1,523,821	3,081,134	2,448,081	160,756	556.1	1,501,471	481,212	966,353	235.4	17,187	272,886	37.0	59,260	123,826
Tennessee	4,246,309	2,105,454	4,978,949	4,004,621	333,219	192.2	1,586,094	176,547	1,313,146	55.7	2,195	412,890	9.1	62,946	46,199
Texas	11,588,643	6,858,253	12,754,565	11,174,336	983,267	1,117.7	5,152,015	387,981	4,564,420	373.0		658,163	47.1	26,326	652,404
Utah	2,367,205	1,066,345	3,145,038	2,324,852	553,524	273.9	506,372	37,000	360,550	29.1		15,000	1.1	5,353	137,271
Vermont	928,184	466,042	987,200	911,184	34,775	48.0	391,632	10,670	353,388	17.7		68,421	1.7	6,330	9,457
Virginia	3,731,207	1,916,178	4,081,114	3,322,846	469,945	165.0	1,514,335	233,865	1,101,176	77.2	51,680	189,121	13.4	122,815	155,937
Washington	3,057,934	1,553,206	3,056,123	2,794,489	200,521	106.4	1,560,705	227,922	1,212,203	23.6		130,299	.3	35,524	10,183
West Virginia	2,013,405	1,140,167	2,138,931	1,901,842	195,860	79.3	513,824	57,156	456,668	17.2	54,407	119,087	4.7		368,552
Wisconsin	4,697,518	1,818,970	4,589,510	4,220,288	151,271	214.8	2,056,979	445,827	1,531,644	87.5	25,000	92,796	6.8	6,403	43,259
Wyoming	2,250,663	1,686,368	2,679,692	2,064,028	452,284	515.8	1,239,296	182,391	1,030,740	196.8		158,392	20.9	4,243	44,952
District of Columbia															
Hawaii	1,693,344	598,778	829,029	526,724		19.3	1,331,572	1,126,855		20.3	20,973	273,416	1.7	18,793	325,362
TOTALS	185,235,236	94,139,083	201,675,656	162,058,916	16,768,453	13,337.6	88,262,779	20,330,843	57,996,367	4,002.6	961,632	10,071,498	675.1	1,883,845	9,302,765

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JUNE 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 1,875,533	$ 1,768,480	$ 98,284	46.1	$ 851,205	$ 568,564	$ 282,641	26.1	$ 29,878	$ 134,766	2.0	$ 23,006	$ 549,270
Arizona	756,982	305,191	680,103	623,659	37,303	14.2	107,877		95,500	.6	129,322	110,505	.2	4,001	61,883
Arkansas	1,964,534	857,025	1,770,332	1,599,134	70,342	44.4	577,173	248,967	326,804	10.6	101,076	200,694	4.5	15,357	259,186
California	4,213,986	2,219,360	4,735,403	3,849,724	258,050	60.2	3,400,728	356,840	1,749,826	13.4		100,000	1.6	7,422	111,484
Colorado	1,718,633	190,000	1,938,348	1,675,081	169,411	39.9					15,949		.8	27,602	29,589
Connecticut	802,407	426,500	838,549	802,407	9,362	10.2	193,692		142,521	1.6		134,613	1.3		140,004
Delaware	460,409	230,849	520,332	460,282	51,542	7.3	40,288		40,288	1.8				127	139,019
Florida	1,453,648	501,200	1,836,588	1,437,885	102,827	21.4	157,148	2,898	154,250	1.4				18,865	244,123
Georgia	2,724,620	1,278,373	2,268,156	2,200,120	35,648	70.0	730,891	308,554	405,049	21.2		143,961	3.0	215,947	[illegible]
Idaho	1,197,829	321,126	1,161,507	1,107,063	11,572	20.1	251,554	45,372	204,994	1.3				45,394	104,560
Illinois	7,381,910	2,230,350	6,418,737	6,122,746		66.4	2,212,287	1,202,054	1,016,233	11.1	47,200	613,518	3.2	3,351	[illegible]
Indiana	4,237,050	2,136,306	3,188,039	3,034,021	14,012	63.8	2,071,711	1,073,165	996,082	28.3	148,115	835,239	11.9	31,749	290,373
Iowa	2,614,472	1,311,000	2,174,064	2,013,668	71,035	57.4	1,493,395	600,765	795,665	23.4		158,535	1.4	39	285,765
Kansas	2,522,401	1,432,949	2,735,303	2,401,599	176,992	42.3	1,332,164	71,884	1,244,977	14.8	48,918	10,980	1.2		
Kentucky	1,927,828	958,599	1,495,742	1,416,934	27,428	34.2	895,386	450,854	435,366	8.7	30,000	215,702	3.9	30,041	280,102
Louisiana	1,708,577	744,560	810,261	744,921	61,391	20.2	1,261,370	946,157	273,172	17.6	10,666	272,960	3.6	6,334	137,037
Maine	960,426	484,179	830,661	825,162		16.4	264,446	67,228	197,218	3.0	58,912	280,254	3.3	9,123	6,908
Maryland	891,132	452,515	390,021	384,017		3.6	1,075,978	262,457		.9				244,559	452,515
Massachusetts	5,007,199	847,600	2,143,777	2,102,232		13.4	3,131,553	2,876,372	230,206	5.8		38,077	.7	28,595	579,318
Michigan	3,500,637	1,613,142	3,343,570	3,104,881	104,400	39.6	1,686,250	357,250	1,291,100	17.8	19,400	120,500	2.3	19,107	97,142
Minnesota	3,719,143	1,421,494	3,479,627	3,140,756	288,822	110.8	1,052,213	520,813	436,917	17.8	2,310	12,581	1.3	55,264	683,174
Mississippi	1,744,669	354,022	1,007,091	897,960	95,559	32.0	945,865	764,058	106,745	26.8	9,152	30,897	1.6	73,498	120,822
Missouri	4,019,501	919,152	2,939,422	2,844,981	18,791	51.9	1,225,029	1,022,062	157,129	11.2		743,232	5.4	152,458	
Montana	1,115,962	113,092	1,057,941	1,012,209	32,919	34.0	125,031	66,068	31,671	6.6	30,012	7,553	3.0	7,673	40,949
Nebraska	1,957,240	991,091	2,272,456	1,917,390	320,655	40.9	531,566		531,566	8.9		344		39,850	138,525
Nevada	500,051	100,000	529,131	473,901	49,331	10.2	8,511		8,511	.6				26,150	40,157
New Hampshire	740,335	242,465	774,421	668,776	102,288	16.9	150,945	71,559	79,176	3.9		50,935	.3		10,066
New Jersey	3,117,921	1,809,500	2,956,249	2,828,272	3,316	22.9	1,062,365	182,690	641,127	5.1		104,946		106,959	1,060,111
New Mexico	1,674,158	529,506	1,651,781	1,471,120	180,097	39.0	192,758	123,326	69,432	2.9	1,010			78,702	279,477
New York	8,255,661	3,756,621	7,926,871	7,168,742	338,700	60.4	4,116,341	887,217	3,009,990	25.9	76,700	62,000		123,002	345,931
North Carolina	2,380,573	1,210,236	2,669,957	2,125,249	536,087	91.7	627,695	122,144	472,005	16.6	91,217	135,600	3.9	41,963	66,544
North Dakota	1,461,112	734,741	1,079,198	1,070,593	1,164	46.7	396,262	238,527	157,735	15.3	119,305	177,547	19.4	22,588	338,296
Ohio	4,335,686	2,359,504	4,874,050	4,238,314	163,665	65.1	1,661,797		1,533,452	15.4	93,352	191,200	2.4	4,020	471,186
Oklahoma	2,304,200	1,171,295	2,377,598	2,098,728	199,102	48.3	744,578	167,849	573,544	8.5	35,871	129,271	2.7	1,752	264,379
Oregon	1,526,724	867,977	1,574,266	1,424,031	103,907	31.2	666,463	66,635	591,819	10.9	518	80,000	.2	34,540	[illegible]
Pennsylvania	4,854,988	2,397,703	4,868,578	4,197,457	505,373	69.4	1,687,812	592,457	972,115	15.1		288,881	.9	66,074	[illegible]
Rhode Island	579,625	285,760	519,890	518,991		7.4	141,760		141,760	1.5				60,634	[illegible]
South Carolina	1,364,731	488,000	1,095,076	1,092,876		34.5	429,543	252,617	171,376	15.3	19,298	103,791	1.2		[illegible]
South Dakota	1,502,870	761,911	1,072,130	1,070,366	1,361	36.8	342,653	183,142	159,511	10.4	55,948	104,395	7.1	133,413	[illegible]
Tennessee	[illegible]	1,121,789	1,875,660	1,740,186	116,431	25.9	760,139	371,898	388,241	6.8	11,071	355,677	3.8		281,441
Texas	6,542,863	1,795,000	5,384,528	5,093,601	167,665	128.8	2,135,160	1,244,952	713,846	22.4	52,836	476,685	13.1	281,474	[illegible]
Utah	778,826	533,173	775,662	649,146	63,066	20.2	500,781	129,130	315,800	9.4		152,000	4.8	590	[illegible]
Vermont	500,509	240,611	566,604	460,328	36,000	14.4	190,448	26,802	149,376	3.3		27,844	.9	13,780	[illegible]
Virginia	1,948,780	956,021	1,502,927	1,250,265	215,043	30.4	1,312,724	634,441	368,146	9.2	13,975	288,433	7.6	5,049	54,733
Washington	1,977,260	776,603	2,250,860	1,922,046	305,761	40.4	455,395	48,798	406,597	7.0		43,513	.2	6,415	20,772
West Virginia	1,342,270	570,085	1,070,754	1,005,009	28,109	17.7	322,153	307,661	14,492	4.2	28,642	216,075	4.0	967	[illegible]
Wisconsin	2,596,143	1,379,513	2,601,041	2,401,818	123,789	55.5	1,107,316	113,025	994,291	15.1	57,664	238,352	4.7	23,635	[illegible]
Wyoming	1,125,332	29,416	977,168	971,191	2,784	22.5	155,723	141,009	14,132	3.0	6,658		.4	6,473	[illegible]
District of Columbia	940,446	181,051	877,332	696,281	181,051	6.5	250,164	250,164		.2					
Hawaii															
TOTALS	115,617,401	47,703,317	103,763,295	94,124,599	5,480,435	1,903.5	45,040,286	17,968,425	23,092,394	508.7	1,345,035	7,392,162	134.4	2,174,342	11,738,126

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JUNE 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933, 1934 Fund	Act of June 18, 1934, 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,03[illegible],452	$ 1,064,960	$ 1,579,597	$ 1,482,576	$ 92,974	116.2	$ 1,142,906	$ 507,248	$ 635,658	76.3		$ 194,367	12.0	$ 42,628	$ 141,962
Arizona	599,423	998,032	766,744	531,273	186,413	65.3	768,207		694,494	63.5	$ 45,000	10,000	7.1	23,150	107,124
Arkansas	1,449,634	857,024	1,249,714	1,243,182		149.1	686,580	152,569	531,639	87.4		173,441	24.4	53,884	151,944
California	3,480,440	1,999,203	3,631,530	2,984,134	37,900	170.4	1,925,434	494,606	1,283,365	58.6		455,377	14.8	1,700	222,560
Colorado	1,718,632	871,502	2,252,224	1,605,435	277,324	232.0	806,909	110,000	504,962	76.8	3,197	89,216	1.2		
Connecticut	659,120	420,868	192,666	160,281	12,889	3.5	727,514	498,839	222,880	16.0					185,099
Delaware	481,113	230,849	428,692	265,666	155,213	51.5	296,824	215,448	70,330	19.9					5,305
Florida	1,302,816	1,043,543	1,620,458	1,284,727	322,934	88.5	580,944		580,944	34.4		103,591	6.8	16,088	36,075
Georgia	2,320,973	1,278,373	1,623,725	1,604,794		123.1	963,710	620,787	342,923	70.9		158,613	5.9	95,391	776,8[illegible]7
Idaho	1,1[illegible]1,562	824,450	1,407,455	1,094,530	135,240	164.1	510,166		510,166	59.6				27,032	179,044
Illinois	5,780,033	4,282,273	3,073,728	3,035,676		160.0	5,732,152	2,727,238	3,004,914	311.9	9,848	994,669	27.4	7,271	282,690
Indiana	731,872	135,970	425,394	386,212		44.2	388,720	310,433	78,287	50.0		30,839	5.7	35,227	26,844
Iowa	2,413,358	1,590,000	2,623,739	2,241,349	315,850	413.4	1,608,508	171,302	1,222,625	270.6		51,400	16.3	707	125
Kansas	2,522,401	1,330,595	2,229,491	2,085,242	141,391	227.8	1,574,717	393,660	1,181,057	84.7	43,499	8,147	1.6		
Kentucky	1,837,926	1,557,503	2,153,944	1,750,680	275,369	238.2	1,337,008	67,733	1,191,635	168.7		49,903	4.7	19,513	40,595
Louisiana	1,426,879	838,953	1,146,988	1,035,963	101,176	50.5	849,730	260,030	589,700	38.8	127,388	129,772	9.3	3,499	18,305
Maine	842,479	445,012	1,246,208	842,404	319,279	98.4	155,427		117,980	8.0				75	7,753
Maryland	891,132	1,067,934	870,902	781,556	41,223	59.5	477,913	99,746	378,167	24.3	9,800	176,376	4.1	30	472,168
Massachusetts	488,185	920,000	477,470	469,741		15.2	415,063		415,063	10.4		115,369	5.5	18,443	389,567
Michigan	3,184,057	1,613,142	3,145,400	2,906,940	39,700	205.7	1,699,244	241,227	1,458,017	82.0		115,425	12.9	35,890	
Minnesota	2,376,415	1,470,324	2,762,148	2,194,840	484,889	299.4	1,079,216	149,444	824,872	100.2		70,695	7.7	32,131	89,868
Mississippi	1,744,669	354,023	1,175,847	1,165,847	10,000	130.2	605,813	543,534	62,279	50.7		133,134	14.1	35,288	148,610
Missouri	2,923,273	2,363,922	3,001,615	2,686,006	239,273	648.8	1,716,231	235,551	1,426,306	302.7		698,343	110.6	1,715	
Montana	1,859,937	942,434	2,165,413	1,751,641	405,178	264.2	438,840		438,840	46.2		42,981	5.2	108,296	55,435
Nebraska	1,957,240	991,091	2,429,004	1,957,240	456,960	420.9	430,845		430,845	67.8		37,136	4.6		66,151
Nevada	1,136,479	852,000	1,493,280	1,113,353	352,874	185.4	244,478		244,478	24.5	20,813		11.2	2,312	254,648
New Hampshire	477,386	261,593	537,176	448,386	43,004	25.7	239,542	29,000	206,408	8.9					12,181
New Jersey	55,099	460,000	56,528	55,099		.5	107,525		107,525	1.7					352,475
New Mexico	1,272,129	735,425	1,497,633	1,235,198	262,435	241.2	420,632	36,931	383,701	55.6		73,135	2.6		16,154
New York	3,608,768	3,822,700	3,680,845	3,035,560	209,289	93.0	4,594,770	515,500	3,403,050	283.5				57,708	210,362
North Carolina	2,380,573	1,700,340	2,649,116	2,187,037	458,052	289.9	1,127,187	160,265	966,922	125.7		120,717	5.4	33,270	154,649
North Dakota	1,451,112	734,742	1,060,224	1,013,518	46,074	322.4	345,193	303,198	41,995	109.0	78,423	196,748	70.7	55,973	449,925
Ohio	3,871,148	1,966,253	4,114,608	3,754,142	101,950	311.8	1,473,086	32,860	1,390,843	95.9	17,000	27,200	8.2	67,145	446,260
Oklahoma	2,304,199	1,171,295	2,210,713	2,032,584	50,770	271.3	1,284,518	265,838	854,360	53.7		91,283	8.7	5,777	174,883
Oregon	1,526,724	777,096	2,098,916	1,501,341	419,957	152.5	431,077	19,526	357,139	21.9				5,858	
Pennsylvania	7,344,822	2,639,003	6,655,128	6,260,219	225,687	554.7	3,445,212	1,066,649	2,275,714	200.4				17,954	137,602
Rhode Island	439,716	254,040	449,748	439,716		33.1	212,563		212,563	6.7		36,815	1.4		4,663
South Carolina	1,364,791	1,342,000	1,186,390	1,086,655	99,102	124.4	1,342,330	227,518	1,076,463	158.9	36,000	99,940	14.2	14,619	66,495
South Dakota	1,502,870	761,911	1,348,466	1,270,007	78,373	397.4	521,851	232,863	288,988	133.6		228,183	71.1		166,368
Tennessee	2,123,155	1,075,748	1,803,755	1,612,243	124,458	132.6	997,727	429,040	568,687	51.3	17,895	106,609	6.0	63,978	275,994
Texas	6,012,518	3,638,000	6,857,715	5,954,262	448,006	850.8	2,893,134	16,517	2,876,597	168.0	18,000	226,000	28.2	23,740	87,397
Utah	1,048,677	533,173	1,353,700	954,655	192,800	195.4	479,682	94,022	314,372	71.1		25,000	2.9		1,000
Vermont	438,880	241,354	563,155	438,631	57,504	39.5	197,199		182,947	13.7				248	903
Virginia	1,736,770	893,188	1,656,585	1,567,019	22,310	211.8	694,412	104,247	582,892	64.6	65,504	239,411	23.7		48,575
Washington	1,080,673	776,603	1,334,664	1,080,673	226,229	100.8	556,610		549,109	24.1					1,265
West Virginia	1,118,559	570,083	770,892	726,068		42.0	688,309	387,152	301,157	26.8		93,524	9.9	5,339	175,402
Wisconsin	2,431,220	1,743,354	2,347,060	2,158,518	48,583	170.4	1,822,266	258,460	1,361,660	60.2		213,229	6.2	14,242	119,881
Wyoming	1,125,332	571,928	1,200,238	1,047,458	135,376	156.8	365,568	33,494	332,063	75.5	41,790	83,412	44.9	2,591	21,077
District of Columbia	972,024	792,791	1,138,516	972,024	166,491	10.2	337,625		337,625	2.7					288,675
Hawaii	177,718	351,000	178,209	177,718		4.9									351,000
TOTALS	93,147,363	58,157,600	91,923,356	79,670,019	7,820,499	9,358.6	51,741,117	12,012,475	37,415,206	4,018.4	534,157	5,700,000	617.2	930,712	7,221,895

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933.

Report of the Chief of the Bureau of Public Roads, 1934.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF JUNE 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Section 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 9,696,610	$ 6,621,629	$ 227,147	502.4	$ 4,158,750	$ 1,606,073	$ 2,153,812	226.4	$ 67,343	$ 788,562	29.6	$ 75,086	$ 1,090,321
Arizona	5,211,960	2,541,935	6,420,017	4,987,449	682,620	432.1	1,859,078		1,660,047	106.5	174,322	120,505	7.4	50,189	178,763
Arkansas	6,748,335	3,428,049	6,427,947	5,360,304	405,433	358.5	3,167,080	1,044,751	1,832,157	188.0	259,995	513,032	38.7	83,285	677,427
California	15,607,354	7,932,206	19,346,404	14,586,686	771,950	594.7	8,513,863	1,010,186	5,152,966	133.2		1,381,651	37.8	10,432	625,519
Colorado	6,874,530	3,486,006	9,300,724	6,628,457	2,075,726	514.8	1,764,886	192,697	1,291,185	121.2	25,774	89,216	7.6	27,602	29,480
Connecticut	2,865,740	1,454,868	1,825,641	1,754,612	22,251	28.3	2,334,760	1,110,133	920,127	41.0		134,613	1.3	496	377,877
Delaware	1,819,088	923,395	2,154,854	1,594,418	524,293	104.4	475,634	220,421	244,168	24.9	4,082	7,442		157	147,493
Florida	5,231,834	2,661,343	6,746,721	4,936,859	690,181	235.5	1,602,868	223,733	1,341,528	66.1		318,061	8.6	71,181	311,573
Georgia	10,091,185	5,113,491	8,475,106	7,726,202	460,299	512.1	3,905,375	1,908,059	1,897,004	197.2	6,394	543,235	13.6	450,531	2,212,452
Idaho	4,486,249	2,277,486	4,822,148	4,228,706	300,840	382.7	1,365,059	177,130	1,160,333	94.3		283,676	13.7	80,412	532,637
Illinois	17,570,770	8,921,401	12,073,723	11,551,012	142,890	266.6	11,941,012	5,931,974	6,009,038	390.1	60,108	1,886,285	31.0	27,677	883,188
Indiana	10,037,843	5,088,963	7,223,398	6,872,150	49,329	220.8	6,332,464	2,811,506	3,353,995	241.6	226,066	1,249,258	39.4	128,122	436,381
Iowa	10,055,660	5,118,361	9,937,052	8,975,947	701,505	788.2	5,431,913	1,078,967	3,733,819	412.1		266,435	21.7	746	416,602
Kansas	10,089,604	5,117,675	10,881,431	9,491,234	1,098,403	907.4	4,553,128	497,074	3,972,957	224.7	92,417	46,315	4.2	8,373	
Kentucky	7,517,359	3,818,311	7,471,304	6,546,919	439,783	553.0	3,425,792	835,100	2,419,540	234.0	30,000	439,913	19.9	105,340	349,075
Louisiana	5,828,591	2,963,932	4,662,318	4,076,249	203,254	147.6	3,731,908	1,575,091	1,961,572	85.4	149,123	404,058	13.0	28,128	395,048
Maine	3,369,917	1,711,586	3,634,361	3,101,229	412,398	162.2	1,032,342	185,162	809,733	21.1	58,912	472,542	10.7	24,613	16,313
Maryland	3,564,527	1,810,158	2,128,302	1,957,068	115,872	78.6	2,529,694	1,159,435	556,739	46.5	116,446	176,376	5.2	331,573	961,072
Massachusetts	6,597,100	3,350,474	4,087,571	3,621,003		66.0	4,641,014	2,929,059	1,635,157	36.4		158,797	6.2	47,038	1,556,520
Michigan	12,736,227	6,452,568	11,745,416	10,933,362	225,500	479.5	6,833,094	1,674,277	5,100,558	235.5	19,400	814,950	41.8	109,188	311,559
Minnesota	10,656,569	5,425,551	12,022,867	9,571,380	2,139,235	1,320.3	3,061,394	862,504	1,998,906	237.8	52,792	367,905	50.6	169,893	919,504
Mississippi	6,978,675	3,540,227	7,322,755	4,585,516	596,242	431.5	4,422,558	2,201,403	1,492,278	237.6	14,727	848,609	50.2	177,030	603,098
Missouri	12,180,306	6,173,740	10,824,108	9,826,887	258,063	898.8	5,858,430	2,119,202	3,460,501	398.7		2,455,176	156.9	234,217	
Montana	7,439,748	3,769,734	9,663,148	7,167,471	2,004,378	862.7	1,645,773	70,197	1,446,207	124.4	30,012	180,179	8.3	172,068	138,970
Nebraska	7,828,961	3,964,364	9,854,651	7,763,472	914,899	831.2	3,087,355	25,639	2,711,123	181.7		78,297	5.1	39,850	260,045
Nevada	4,545,917	2,302,356	5,382,730	4,270,430	1,007,087	518.1	940,086	187,644	751,774	124.8	55,722	234,342	71.5	32,122	309,152
New Hampshire	1,909,839	969,462	2,039,902	1,729,551	234,565	55.2	843,738	180,288	637,716	23.5		50,935	.3		46,247
New Jersey	6,346,039	3,220,879	5,244,520	4,909,216	18,316	60.8	2,956,057	1,295,764	1,324,259	22.0		115,113		141,059	1,763,191
New Mexico	5,792,935	2,941,700	6,854,286	5,454,404	1,254,992	644.0	1,290,424	258,819	1,016,079	103.6	1,010	374,499	21.2	78,702	296,131
New York	22,330,101	11,327,921	23,149,575	19,215,590	778,219	377.4	16,256,421	2,665,189	9,659,592	446.7	76,700	88,900		372,622	801,211
North Carolina	9,522,293	4,840,941	10,273,304	7,929,100	1,384,845	984.3	3,261,528	1,068,960	1,967,616	299.0	155,667	623,585	28.3	368,567	864,894
North Dakota	5,804,448	2,938,967	5,397,306	4,687,077	264,914	1,491.5	1,423,871	638,796	609,045	327.9	346,084	629,392	247.7	132,491	1,435,617
Ohio	15,484,592	7,865,012	16,507,808	15,032,692	353,715	572.0	6,509,609	218,941	5,778,808	180.4	153,152	221,820	11.4	79,807	1,510,669
Oklahoma	9,216,798	4,685,180	9,310,378	8,332,339	634,015	637.7	4,066,331	829,870	2,856,440	142.2	46,690	587,704	22.6	7,898	607,021
Oregon	6,106,896	3,097,814	7,288,385	5,868,344	803,811	377.7	2,401,907	166,751	2,052,810	88.1	518	80,000	.2	71,283	161,193
Pennsylvania	18,891,004	9,590,788	18,581,377	16,648,281	1,324,139	763.9	9,563,758	2,101,137	7,005,393	296.6	2,126	295,697	.9	139,460	965,558
Rhode Island	1,998,708	1,014,572	1,937,643	1,858,334		61.1	914,914	79,740	818,895	22.5		36,815	1.4	60,634	158,863
South Carolina	5,459,165	2,770,954	4,817,608	4,539,153	211,067	376.0	2,438,919	795,765	1,599,254	229.9	73,818	230,951	15.7	50,430	729,632
South Dakota	6,011,479	3,047,643	5,501,730	4,788,454	240,490	990.2	2,365,975	897,217	1,414,851	379.3	73,135	605,465	115.1	252,673	786,838
Tennessee	8,492,619	4,302,991	8,658,365	7,357,050	574,108	350.7	3,343,960	977,485	2,270,074	113.8	31,160	875,175	18.9	126,924	583,634
Texas	24,244,024	12,291,253	24,996,808	22,222,198	1,598,937	2,097.3	10,180,309	1,649,450	8,154,862	563.4	70,836	1,360,848	88.4	301,540	1,176,605
Utah	4,194,708	2,132,691	5,274,400	3,928,652	809,391	489.4	1,486,835	260,153	990,723	109.6		192,000	8.8	5,903	140,577
Vermont	1,867,573	948,007	2,116,960	1,810,143	128,279	101.8	779,279	37,472	685,712	34.7		96,266	2.6	19,958	37,750
Virginia	7,416,757	3,765,387	7,240,626	6,140,130	707,298	407.3	3,521,472	972,554	2,052,213	151.1	131,159	716,970	44.7	172,914	288,905
Washington	6,115,867	3,106,412	6,641,647	5,797,208	732,511	247.6	2,572,710	276,720	2,167,910	54.7		173,812	.5	41,939	32,180
West Virginia	4,474,234	2,280,335	3,980,577	3,632,919	223,969	139.0	1,524,286	751,970	772,316	48.3	83,049	428,686	18.5	6,296	855,363
Wisconsin	9,724,881	4,941,837	9,537,611	8,780,624	323,642	440.8	4,986,561	817,312	3,887,595	162.8	82,664	544,377	17.7	44,280	186,222
Wyoming	4,501,327	2,287,712	4,857,099	4,082,677	590,444	695.1	1,760,587	356,894	1,376,935	275.3	48,448	241,804	66.1	13,307	78,529
District of Columbia	1,918,469	973,842	2,015,847	1,668,305	347,542	16.7	587,789	250,164	337,625	2.8					288,675
Hawaii	1,871,062	949,778	1,007,238	704,442		24.2	1,331,572	1,126,855		20.3	20,973	273,416	1.7	18,793	676,362
TOTALS	394,000,000	200,000,000	397,362,307	335,853,534	30,069,387	24,599.7	185,044,182	50,311,743	118,503,967	8,529.7	2,840,824	23,163,660	1,426.7	4,993,899	28,262,986

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BUREAU OF PUBLIC ROADS

VOL. 16, NO. 6 ▽ AUGUST 1935

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

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BUREAU OF PUBLIC ROADS

Volume 16, No. 6 August 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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FURTHER STUDIES OF LIQUID ASPHALTIC ROAD MATERIALS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by **R. H. LEWIS** Associate Chemist, and **W. O'B. HILLMAN**, Assistant Highway Engineer

IN A REPORT recently published by the Bureau of Public Roads on A Study of Some Liquid Asphaltic Materials of the Slow-Curing Type,[1] it was shown that the action of sunlight, heat, and air on these materials when exposed in relatively thin films produced residues with physical and chemical characteristics differing greatly from those of the residues developed in the usual laboratory heat tests. It was also shown that when these materials were mixed with a standard sand, molded into cylinders by the Hubbard-Field method, and subjected to the same exposure conditions as the thin films, they developed stability, or bonding strength that could not be attributed entirely to the loss of volatile matter.

MATERIALS STUDIED TYPICAL OF ALL CLASSES OF LIQUID ASPHALTIC MATERIALS FROM PRINCIPAL PRODUCING AREAS

The materials used in the earlier investigation were slow-curing liquid asphalts. They were the products of 10 refineries located in the far and middle West. In further studies conducted in 1933, that are the subject of this report, 32 materials typical of the slow-, medium-, and rapid-curing types of liquid asphaltic materials were used. These samples are identified in table 1 and were the products of 25 refineries located in all sections of the country and probably were made from petroleums of widely different bases and by various refining processes.

TABLE 1.—*Products tested*

Sample identification	Laboratory number	Type of material	Producer	Refinery	Location of refinery	Remarks
1	36626	SC-2	1	1	Oklahoma	
2	34354	SC-2	2	2	Missouri	
3	35130	SC-2	2	3	Illinois	
4	35481	SC-3	3	4	do	
5	36425	SC-3	3	5	Wyoming	
6	36045	SC-3	4	6	Arkansas	
7	36945	[1] SC-2	5	7	do	
8	36598	SC-2	6	8	Oklahoma	
9	35195	[1] SC-2	7	9	West Virginia	
10	35334	[1] SC-2	8	10	Rhode Island	
11	35200	[2] SC-1	9	11	Louisiana	
12	35396	[1] SC-2	9	11	do	
13	36026	SC-3	9	11	do	
14	35351	SC-2	2	12	Indiana	
15	35180	SC-2	2	13	Wyoming	
16	35181	SC-2	2	14	do	
17	35103	SC-2	10	15	Indiana	Included in 1932 exposure.
18	35367	SC-2	10	16	Illinois	do.
19	34322	SC-2	11	17	do	do.
20	36089	SC-2	12	18	California	do.
21	39161	SC-2	13	19	do	Steam-reduced California residual oil.
22	39162	[2] SC-3	13	19	do	
23	39068	[1] SC-2	7	20	South Carolina	
24	34285	RC-2	14	21	New Jersey	
25	36762	[2] RC-2	3	22	do	
26	35345	RC-2	2	12	Indiana	
27	35352	[2] MC-1	2	12	do	
28	35247	RC-2	7	23	Maryland	
29	36771	RC-2	15	24	do	
0	33607	[3] MC-2	16	25	Wyoming	
1	32916	MC-2	2	13	do	
2	32622	MC-2	13	19	California	

[1] Furol viscosity was below specification limit.
[2] Furol viscosity was above specification limit.
[3] Penetration of distillation residue was below specification limit.

As shown in table 1, 23 of the materials were of the slow-curing type, of which 4 samples were tested in 1932 and were included in this study for comparative purposes. Four were of the medium-curing type and five were rapid-curing products. They met the provisional specifications, as given in table 2, of the Bureau of Public Roads and the Asphalt Institute, except as noted in table 1. Samples 21 and 22 were the only slow-curing products for which there was any definite information as to origin or method of manufacture. Both of these materials were steam-reduced California residuals without subsequent blending. All of the rapid-curing products were prepared from 85–100 penetration asphalt and solvent naphtha. The composition of sample 27 was unknown but the other medium-curing products, samples 30, 31, and 32, were, respectively, 110–120 penetration asphalt, 94+ asphaltic road oil, and 100–120 penetration asphalt fluxed with a heavy grade of kerosene. These three medium-curing materials, although subjected to all of the laboratory tests, were exposed only under special conditions that are described later in this report.

TABLE 2.—*Specification requirements for grades of liquid asphaltic road materials investigated*

	SC-1	SC-2	SC-3	MC-1	MC-2	RC-2
Flash point, °F.	150+	200+	200+		150+	[illegible]
Furol viscosity at 77° F., seconds	20–150			40–150		
Furol viscosity at 122° F., seconds		200–320				[illegible]
Furol viscosity at 140° F., seconds			[illegible]		150–250	
Total distillate to 437° F., percent by volume		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total distillate to 600° F., percent by volume		[illegible]	10–	[illegible]	[illegible]	20+
Total distillate to 680° F., percent by volume	50–	25–	20–	[illegible]	[illegible]	35–
Tests on distillation residue:						
Float at 122° F., seconds	[illegible]	25+	[illegible]			
Penetration at 77° F.				[illegible]	[illegible]	[illegible]
Ductility at 77° F., centimeters				60+	[illegible]	[illegible]
Soluble in CS_2, percent	99.0+	99.0+	[illegible]	[illegible]	[illegible]	[illegible]

The test procedure followed that of the 1932 study except that the fixed-carbon test was omitted as the changes in inherent characteristics that occurred under laboratory and exposure conditions appeared to be more strikingly illustrated by the test for solubility in 86° B. naphtha. Two new tests were added. The Oliensis test[2] for heterogeneity was made on the original materials and on all of the residues, except those from the 50-gram oven-loss test and the 10-week exposure test, and the original materials were examined microscopically. The results of the tests on the original materials are given in table 3 and a detailed analysis of the residues obtained in the routine laboratory tests is given in table 4.

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[1] R. H. Lewis and W. O'B. Hillman, PUBLIC ROADS, June [illegible]

[2] A qualitative test for [illegible] Oliensis, Proc. A. S. T. M., vol. 33, pp. 715-728.

TABLE 3.—*Results of tests on original materials*

Sample identification	Specific gravity at 77° F.	Flash point	Float at 77° F.	Furol viscosity		Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha	Characteristic by Oliensis test [1]	Microscopic smear test	Distillation												Loss at 325° F., 5 hours						Asphaltic residue	
				At 122° F.	At 140° F.						Initial boiling point	Distillate by volume				Distillate to 680° F. (by weight)	Loss on cooling (by weight)	Total loss (by weight)	Tests on distillate		Float of residue at 122° F.	Penetration of residue at 77° F., 100 g, 5 sec.	50-gram sample			20-gram sample			Time of reduction	Amount of residue
												At 374° F.	At 437° F.	At 600° F.	At 680° F.				Specific gravity at 77° F.	Index of refraction			Loss	Float of residue at 122° F.	Penetration of residue at 77° F., 100 g, 5 sec.	Loss	Float of residue at 122° F.	Penetration of residue at 77° F., 100 g, 5 sec.		
		° F.	Sec.	Sec.	Sec.	Pct.	Pct.	Pct.			° F	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.			Sec.		Pct.	Sec.		Pct.	Sec.		Min.	Pct.
1	0.965	430	100	294	146	----	0.22	6.3	H	Clear	680+	----	----	----	----	----	2.8	2.8	----	----	24	----	0.5	24	----	0.8	27	----	280	71.9
2	1.056	300	52	303	139	0.19	1.11	26.1	H	----	600	----	----	----	8.0	6.4	4.6	11.0	0.911	1.5146	60	----	3.5	35	----	6.6	57	----	40	74.7
3	1.056	330	50	274	123	.11	.46	21.8	H	----	628	----	----	----	3.0	2.4	4.4	6.8	.926	1.5246	43	----	2.6	30	----	4.6	38	----	47	71.7
4	1.043	340	63	404	174	.13	.47	16.5	H	----	625	----	----	----	2.0	1.7	4.0	5.7	----	1.5120	45	----	2.6	39	----	4.5	51	----	60	74.7
5	.998	275	36	331	160	----	.10	13.7	H	Clear	525	----	----	1.3	10.0	8.6	5.0	13.6	.886	1.4930	58	----	5.1	36	----	8.6	57	----	80	70.6
6	.974	340	21	335	170	----	.09	9.4	O	do	594	----	----	----	3.0	2.5	4.9	7.4	----	1.4794	21	----	3.0	17	----	4.9	20	----	236	62.4
7	.960	255	9	181	104	----	.11	10.6	SH	do	515	----	----	7.0	20.5	18.3	5.1	23.4	.868	1.4809	62	----	8.0	18	----	14.3	34	----	140	64.8
8	.957	355	60	277	146	----	.09	6.7	O	do	620	----	----	----	2.0	1.6	4.8	6.4	----	1.4748	27	----	2.1	25	----	3.3	27	----	275	65.3
9	1.032	250	33	175	87	.38	2.39	18.1	H	----	500	----	----	1.0	7.0	5.6	5.3	10.9	.864	1.4858	44	----	4.4	29	----	6.9	45	----	48	69.0
10	.963	160	11	197	110	----	.10	13.9	O	Clear	450	----	----	13.0	19.5	16.9	5.4	22.3	.837	1.4615	87	----	12.7	42	----	16.6	74	----	70	65.9
11	1.010	245	4	50	31	----	.20	7.6	H	do	520	----	----	7.5	22.0	20.5	4.5	25.0	.956	1.5445	34	----	8.8	10	----	15.2	20	----	93	53.2
12	.963	265	13	182	100	----	.09	10.7	O	do	525	----	----	2.5	13.5	12.2	5.7	17.9	.866	1.4770	38	----	6.6	18	----	10.2	27	----	121	61.8
13	1.010	320	41	406	195	----	.09	11.3	H	do	600	----	----	----	5.5	4.8	4.5	9.3	.958	1.5460	37	----	3.7	30	----	6.2	36	----	110	66.8
14	1.060	350	49	278	124	.09	.09	17.6	H	----	665	----	----	----	1.0	.9	4.2	5.1	----	1.5268	36	----	2.4	31	----	4.2	39	----	60	69.5
15	.979	285	21	219	117	----	.08	11.6	O	Clear	580	----	----	.5	12.0	10.2	5.2	15.4	.871	1.4785	41	----	5.0	24	----	8.6	30	----	113	61.7
16	.970	360	38	217	115	----	.11	9.6	SH	do	670	----	----	----	1.0	1.0	5.8	6.8	----	1.4755	25	----	1.9	17	----	3.5	24	----	176	62.0
17	1.013	255	20	205	110	.17	2.17	16.1	H	----	536	----	----	7.0	20.0	16.3	4.3	20.6	.853	1.4714	110	----	8.8	42	----	14.1	112	----	34	71.9
18	.955	200	9	199	106	----	.11	4.6	SH	Clear	482	----	----	13.5	19.3	16.5	1.2	17.7	.821	1.4529	60	----	10.7	26	----	15.6	55	----	420	75.1
19	1.082	300	75	320	137	.08	2.88	25.8	H	----	599	----	----	----	8.3	7.0	2.9	9.9	.937	1.5364	57	----	4.9	48	----	7.9	79	----	30	75.9
20	.960	275	46	300	149	----	.08	7.5	SH	Clear	576	----	----	----	10.8	9.4	4.5	13.9	.849	1.4665	50	----	6.0	34	----	8.3	52	----	103	68.9
21	.972	295	23	293	137	----	.06	5.4	O	do	580	----	----	----	11.0	9.8	5.0	14.8	.890	1.4859	41	----	5.7	26	----	10.7	59	----	83	62.6
22	.976	310	60	768	331	----	.09	6.5	O	do	600	----	----	----	6.0	5.1	4.7	9.8	.889	1.4852	56	----	4.3	42	----	7.7	58	----	83	70.6
23	1.012	260	12	123	63	----	.07	7.9	H	do	530	----	----	1.3	8.5	7.3	4.2	11.5	.882	1.4904	27	----	5.5	22	----	9.1	30	----	97	60.9
24	.972	85	14	241	133	----	.10	17.3	H	do	332	3.0	13.5	23.8	27.0	21.7	3.1	24.8	.799	1.4420	----	76	20.6	----	152	22.2	----	80	13	77.2
25	.946	80	31	472	229	----	.15	20.9	O	do	250	11.5	18.5	25.3	27.5	21.6	2.2	23.8	.763	1.4203	----	77	21.5	----	99	22.4	----	56	14	78.2
26	.949	115	35	351	185	----	.11	18.2	O	do	370	----	11.0	23.8	26.5	21.7	1.7	23.4	.782	1.4320	----	84	20.7	----	113	22.4	----	55	11	78.4
27	.988	170	3	47	30	----	.11	14.5	H	do	420	----	.5	28.0	32.5	27.1	3.0	30.1	.829	1.4606	----	87	22.1	100	----	27.8	----	41	22	72.6
28	.954	80	19	303	170	----	.19	17.6	O	do	270	10.5	18.0	23.0	24.5	19.6	1.5	21.1	.763	1.4256	----	65	19.8	----	85	20.4	----	50	11	80.4
29	.960	80	17	260	148	----	.13	20.8	H	do	----	15.0	21.0	25.5	27.0	21.0	2.5	23.5	.751	1.4156	----	72	21.1	----	94	21.9	----	53	15	78.5
30	.978	200	39	350	173	----	.09	20.8	H	do	430	----	----	21.0	26.5	22.2	3.4	25.6	.837	1.4668	----	81	17.6	186	----	23.8	----	56	16	75.8
31	.994	205	37	431	216	----	.12	19.7	H	do	450	----	----	16.0	21.5	17.3	2.9	20.2	.827	1.4600	----	205	14.5	144	----	19.1	----	100	30	78.9
32	.968	195	25	331	162	----	.15	10.5	SH	do	360	----	----	13.5	21.0	17.9	4.2	22.1	.831	1.4568	----	298	13.6	87	----	18.5	----	235	23	75.0

[1] H = Heterogeneous; O = Homogeneous; SH = Slightly heterogeneous.

DISTILLATION CURVES CLEARLY DISTINGUISH SLOW-, MEDIUM-, AND RAPID-CURING MATERIALS

The distillation curves for the various materials, plotted in figure 1, serve to distinguish the three classes of materials according to their curing properties. It will be noted that the initial boiling points of the slow-curing products, samples 1 to 23, inclusive, were all above 450° F. and in only two instances were they less than 500° F. The medium-curing materials, samples 27, 30, 31, and 32, had initial boiling points as low as 360° F. with none above 450° F.; and the rapid-curing products, samples 24, 25, 26, 28, and 29, all had initial boiling points below 370° F.

With all three classes of materials, the percentage of distillate increased as the temperature increased but not at the same rate. For the slow-curing materials, the rate continued fairly uniform up to 680° F., but with the medium- and rapid-curing products it decreased as the temperature approached 680° F. The decrease in rate was more pronounced for the rapid-curing products. The rate of distillation may be illustrated by expressing the amount of distillate off at any temperature in terms of the total distillate recovered at 680° F. For the medium-curing materials the amount at 600° F. was 65 to 85 percent of the total. For rapid-curing materials the amount was 0 to 50 percent at 374°F., 41 to 85 percent at 437° F., and 88 to 94 percent at 600° F. The residues from the distillation of the slow-curing products were all fluid, while those of the medium- and rapid-curing materials were semisolid.

That portion of the total loss in the distillation test designated as loss on cooling depends upon the amount of material boiling off immediately above 680° F. As would be expected from the slope of the distillation curves, this loss was greater for the slow-curing products than for the medium- and rapid-curing products. It ranged from 1.2 percent to 5.8 percent with an average of 4.5 percent for the slow-curing products, from 2.9 percent to 4.2 percent with an average of 3.4 percent for the medium-curing products, and from 1.5 percent to 3.1 percent with an average of 2.2 percent for the rapid-curing products.

The total volatile matter in the slow-curing materials as determined by the distillation test, including both the distillate recovered and the loss on cooling, ranged from 2.8 percent to 25 percent with an average of 13.8 percent for the group. The average loss on cooling of 4.5 percent actually represented 36 percent of the total volatile matter in the average slow-curing material used in this study. While this loss on cooling may be unimportant in estimating the relative volatility of various liquid asphalts, it must be considered if the results of the distillation test are to be compared directly with the results of other laboratory and exposure tests.

The different classes of materials are also readily identified by the results of the volatilization and asphaltic-residue tests. The slow-curing products lost in the 50-gram volatilization test from 53 to 76 percent, the medium-curing products from 73 to 80 percent, and the rapid-curing products from 92 to 97

TABLE 4.—*Results of tests on laboratory residues*

Sample identification	Distillation										Volatilization at 325° F., 5 hours													Asphaltic residue test								
	Total loss in distillation test	Tests on residue									50-gram sample							20-gram sample						Loss	Penetration		Softening point	Ductility at 5 centimeters per minute		Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B naphtha
		Float at 122° F.	Penetration		Softening point	Ductility at 5 centimeters per minute		Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B naphtha	Loss	Tests on residue						Loss	Tests on residue						At 77° F., 100 g, 5 sec.	At 32° F., 200 g, 60 sec.		At 77° F.	At 39.2° F.			
			At 77° F., 100 g, 5 sec.	At 32° F., 200 g, 60 sec.		At 77° F.	At 39.2° F.					Float at 122° F.	Penetration		Softening point	Ductility at 5 centimeters per minute			Float at 122° F.	Penetration at 77° F., 100 g, 5 sec.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B naphtha									
													At 77° F., 100 g, 5 sec.	At 32° F., 200 g, 60 sec.		At 77° F.	At 39.2° F.															
	Pct.	*Sec.*			° *F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Sec.*			° *F.*	*Cm*	*Cm*	*Pct.*	*Sec.*		*Pct.*	*Pct.*	*Pct.*	*Pct.*			° *F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*
1	2.8	24							0.10	6.9	0.5	24						0.8	27			0.03	9.7	28.1	96	37	125	16	3.5		[illegible]	[illegible]
2	11.0	60						0.16	.81	32.2	3.5	35						6.6	57		0.23	5.05	28.3	25.3	100	15	109	110+	.0	0.16	[illegible]	[illegible]
3	6.8	43						.17	.41	24.3	2.6	30						4.6	38		.19	3.51	23.7	28.3	105	15	107	110+	.0	.16	1.50	[illegible]
4	5.7	45						.15	.34	21.0	2.6	39						4.5	51		.20	1.91	19.7	25.3	107	18	108	110+	.0	.19	1.62	[illegible]
5	13.6	58							.17	16.1	5.1	36						8.6	57			.14	18.9	29.4	103	28	113	100	4.5		.12	24.2
6	7.4	21							.08	10.9	3.0	17						4.9	20			.11	11.9	37.6	99	11	110	110+	[illegible]		.14	22.6
7	23.4	62							.13	14.5	8.0	18						14.3	34			.15	17.2	35.2	92	28	118	110+	.5		.1[illegible]	22.7
8	6.4	27							.10	7.8	2.1	25						3.3	27			.06	10.6	34.7	100	34	114	[illegible]	[illegible]		[illegible]	[illegible]
9	10.9	44						.31	2.37	24.1	4.4	29						6.9	45		1.17	5.31	21.7	31.0	86	17	110	113	.0	.55	[illegible]	[illegible]
10	22.3	87							.11	18.3	12.7	42						16.6	74			.13	19.8	34.1	106	35	117	98	6.0		.12	[illegible]
11	25.0	34							.09	10.3	8.8	10						15.2	20			.14	12.2	46.8	84	21	115	110+	.1		.03	21.1
12	17.9	38							.12	12.7	6.6	18						10.2	27			.10	13.4	38.2	97	35	119	110+	[illegible]		.12	[illegible]
13	9.3	37							.10	11.7	3.7	30						6.2	36			.16	14.1	33.2	93	[illegible]	115	110+	1.0		.09	[illegible]
14	5.1	36						.15	.15	18.0	2.4	31						4.2	39		.26	1.10	20.9	30.5	93	13	110	110+	.0	[illegible]	.72	31.1
15	15.4	41							.10	14.0	5.0	24						8.6	30			.15	15.2	38.3	[illegible]	[illegible]	115	110+	4.5		[illegible]	[illegible]
16	6.8	25							.15	10.7	1.9	17						3.5	24			.21	12.1	38.0	109	36	117	100	[illegible]		.03	[illegible]
17	20.6	110						.38	1.83	21.3	8.8	42						14.1	112		.28	4.88	23.3	28.1	81	15	114	110+	.0	.60	[illegible]	29.2
18	17.7	60							.09	7.2	10.7	26						15.6	55			.02	8.8	24.9	88	27	120	110+	4.8		[illegible]	[illegible]
19	9.9	57						.08	4.54	35.2	4.9	48						7.9	79		.69	7.35	31.4	24.1	92	11	109	110+	.0	.24	.84	39.4
20	13.9	50							.09	9.5	6.0	34						8.3	52			.12	11.1	31.1	102	21	114	110+	.8		.04	[illegible]
21	14.8	41							.13	6.1	5.7	26						10.7	39			.23	8.4	37.4	110	18	109	110+	.6		.04	15.3
22	9.8	56							.09	6.7	4.3	42						7.7	58			.20	9.1	29.4	113	23	109	110+	.0		.05	14.5
23	11.5	27							.12	9.6	5.5	22						9.1	30			.19	11.2	39.1	98	17	110	110+	.0		.05	20.8
24	24.8		76	18	117	110+	0.0		.12	23.0	20.6		152	35	111	110+	9.0	22.2		80		.24	25.5	22.8	101	22	115	110+	[illegible]		.10	[illegible]
25	23.8		77	28	122	110+	4.5		.18	25.4	21.5		99	33	126	110+	4.5	22.4		56		.27	28.4	21.8	91	35	125	110+	[illegible]		[illegible]	25.7
26	23.4		84	28	116	110+	4.0		.12	21.0	20.7		113	30	120	110+	3.8	22.4		55		.16	24.6	21.6	95	32	121	110+	3.8		.08	22.6
27	30.1		87	15	109	110+	.0		.13	26.8	22.1	100						27.8		41	.18	.59	27.5	27.4	90	12	109	110+	.0	[illegible]	.31	25.6
28	21.1		65	20	122	110+	.5		.16	21.8	19.8		85	23	123	110+	.0	20.4		50		.20	24.9	19.6	97	34	118	110+	[illegible]		.06	21.1
29	23.5		72	25	121	110+	4.5		.16	29.0	21.1		94	24	124	110+	4.5	21.9		53		.17	32.8	21.5	100	23	120	110+	[illegible]		.18	[illegible]
30	25.6		81	25	117	99	2.5		.16	29.0	17.6	186						23.8		56		.14	29.5	24.2	104	30	118	110+	4.3		.09	27.1
31	20.2		205	41	101	110+	15.0		.10	24.5	14.5	144						19.1		100		.07	26.3	21.1	112	22	117	110+	4.3		.11	24.9
32	22.1		298	55	93	75	90+		.23	12.2	13.6	87						18.5		235		.13	16.4	25.0	101	16	111	110+	.0		.27	15.7

percent as much as they lost in the 20-gram volatilization test. The residues from both volatilization tests of the slow-curing products were fluid; those of the medium-curing products were fluid in the 50-gram volatilization test and semisolid in the 20-gram volatilization test; and those of the rapid-curing products were both semisolid. For the slow-curing products, the loss in neither volatilization test amounted to as much as that in the asphaltic residue test. For the medium-curing products, the loss in the 20-gram volatilization test approximated the loss in the asphaltic-residue test, while for the rapid-curing products the losses in all tests, including the distillation test, were approximately the same. The loss in the 20-gram volatilization test, while always greater than that in the 50-gram volatilization test, was always less than in the distillation test. The residue from the 20-gram volatilization test may, however, be harder or softer than the residue from distillation.

The slow-curing products were reduced to a residue of 100 penetration in from 30 to 420 minutes, with an average of 126 minutes. In producing residues of the same consistency medium-curing products took from 16 to 30 minutes, with an average of 23 minutes and the rapid-curing products took from 11 to 15 minutes, with an average of 13 minutes. When making the asphaltic-residue test on the rapid-curing products, difficulty was experienced in obtaining a residue that was not too hard, since the high volatility of the solvent caused the cut-back materials to be reduced to 100 penetration before the temperature for making the test was reached.

MAJORITY OF MATERIALS SHOWED A CLEAR FIELD ON MICROSCOPIC EXAMINATION

The microscopic test, adopted by one State highway department for the detection of cracking-coil products, was made on all materials. The specification of the State did not set up an exact procedure. It merely stated that a freshly prepared smear of the asphaltic material diluted with carbon tetrachloride should show a clear field free from carbonaceous matter when subjected to a magnification of 200 diameters. In the work covered by this report, the test was standardized by using 2 parts by weight of carbon tetrachloride and 1 part by weight of asphaltic material in preparing the slides for observation. When prepared in this manner all of the materials but seven showed a clear field. In preparing the slides for the photomicrographs illustrated in figure 2, 6 parts by weight of carbon tetrachloride and 1 of the asphaltic material were used.

Because carbon tetrachloride has both solvent and flocculent properties, its use as a diluent was questioned. Therefore, slides were also prepared with the undiluted materials and it was found that only those materials that showed flecks when undiluted showed

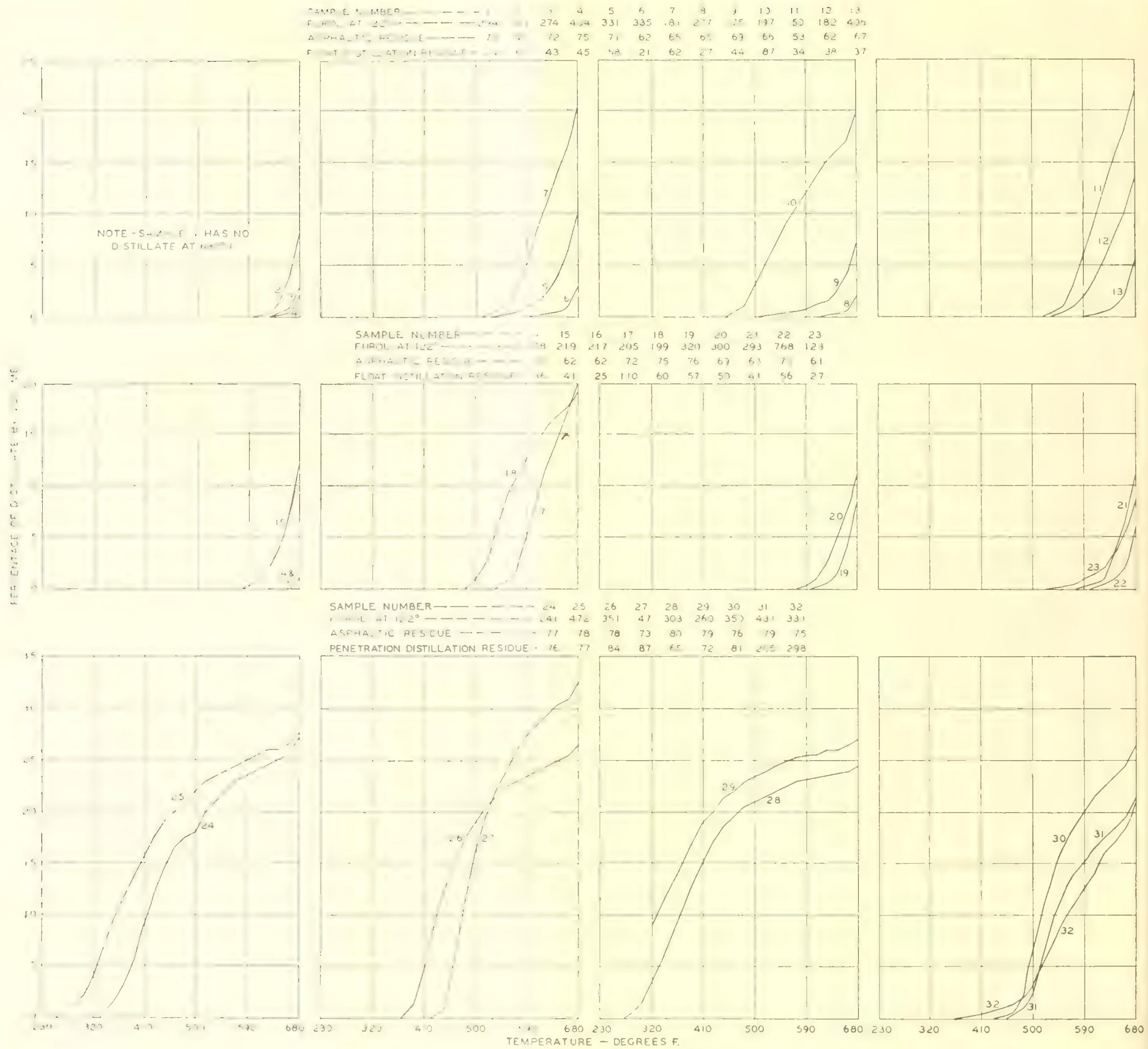

Figure 1.—Relation of Percentage of Distillate by Volume to Distilling Temperature.

them in the 2 to 1 and 6 to 1 dilutions. This indicates that the insoluble matter was already flocculated and that carbon tetrachloride, in the quantities used, did not precipitate carbonaceous flecks in those materials not containing them when undiluted. Recently a sample was tested that contained flecks when undiluted that disappeared on dilution with carbon tetrachloride; and another sample that was practically clear when undiluted contained flecks when diluted. In the first case, the poor solvent properties of the distillate used in the material were responsible for incomplete solution of the base asphalt, that immediately went into solution with the addition of carbon tetrachloride. In the second case it was quite evident that the carbon tetrachloride acted as a flocculent. However, since 6 of the 7 samples that contained carbonaceous material had relatively high percentages of material insoluble in carbon tetrachloride, it is probable that the flecks shown are particles of free carbon and carbenes.

In conducting the exposure tests three samples of each material were placed in seamless, flat-bottom tins having a diameter of 5½ inches and a depth of five-eighths inch. Fifty cubic centimeters of material were used to obtain a uniform film or layer thickness of about one-eighth inch. The samples were then placed in exposure boxes made of wood. A plate-glass cover resting on strips of felt fastened to the edges of each box made a tight joint and excluded all dust and dirt. A current of air was passed through a wash bottle containing sulphuric acid to remove dust and eliminate moisture, and was admitted through the bottom of the boxes and escaped through slots in the sides, thus serving to carry off the vapors formed. The slots were protected from rain by thin boards extending from the top of the box downward at a

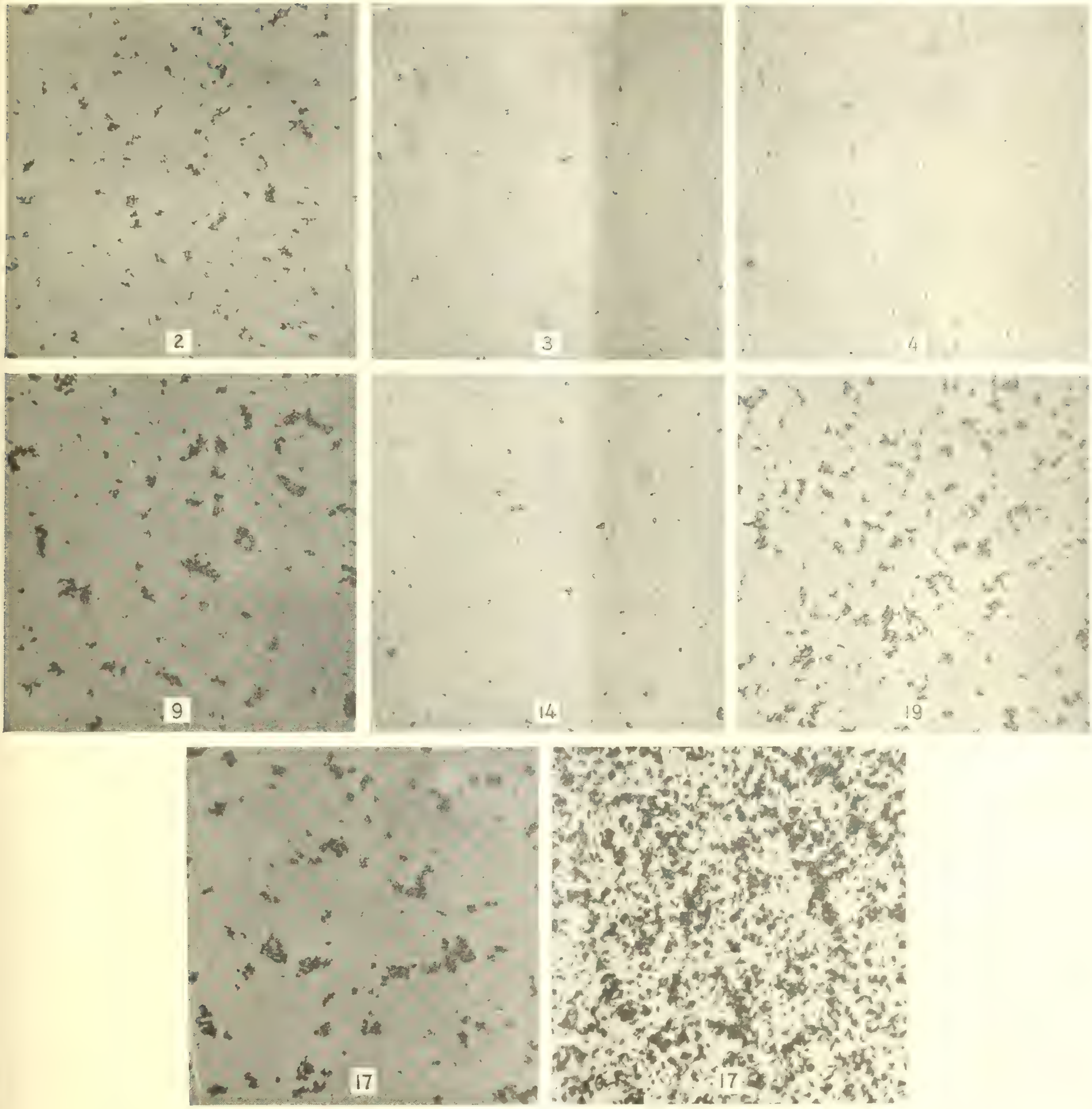

Figure 2.—Photomicrographs of Materials Containing Carbonaceous Matter (Magnified 200 Times). The Lower Two Illustrations Show Results Obtained With Sample 17; in the One on the Left the Material Was Diluted with Carbon Tetrachloride and the One on the Right Shows Undiluted Material.

angle of about 45°. Cotton batting inserted in the slots excluded dust. A thermometer in each box provided a means of determining the temperature. The assembly of the boxes is shown in figure 3.

DIFFERENCES FOUND BETWEEN SLOW-CURING AND CUT-BACK PRODUCTS AFTER EXPOSURE

The samples were placed in the boxes on June 15, 1933, and were weighed periodically to determine the oss in weight. A complete set of samples was removed and tested at the end of 5 weeks, another set at 10 weeks, and the last set at 15 weeks. The temperature of the boxes was dependent entirely upon the radiant heat of the sun and varied with the amount of sunshine. On clear days the temperature was extremely high, the maximum recorded being 196° F., but on days with no sunshine the temperature in the boxes was the same as that of the air. During the period of exposure the average maximum daily air temperature was 85° F. The samples exposed for 5 weeks were subjected to 333 hours of sunlight and those exposed for 10 and 15 weeks were subjected to 611 and 866 hours of sunlight, respectively. The percentage of loss at different periods of exposure is given in table 5 and the results of tests on the residues are given in table 6. Photographs of typical surfaces at the end of 15 weeks are shown in figure 4.

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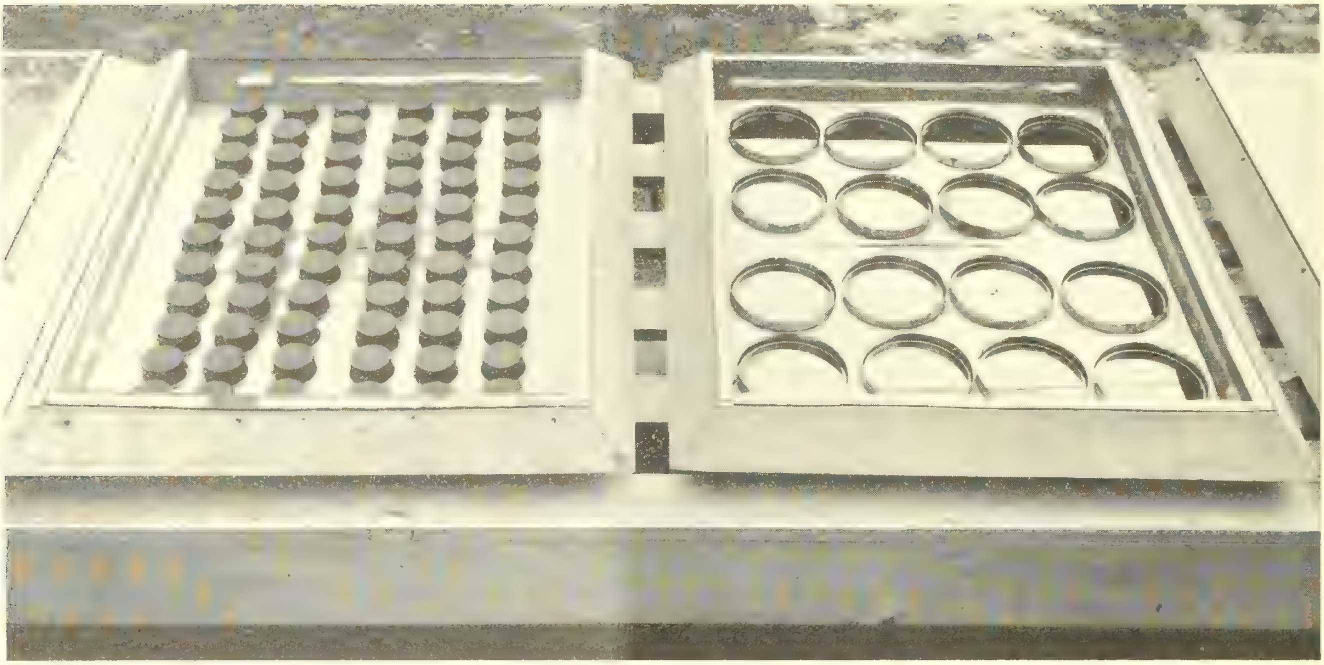

FIGURE 3.—STABILITY SPECIMENS AND THIN FILMS OF MATERIAL EXPOSED TO SUNLIGHT.

While the majority of the materials progressively lost weight during the period of exposure, a number of them actually gained at first, although they later lost more than the amounts gained. An exception to this was sample 1, which had gained 3.6 percent at the end of 8 days and at the end of 15 weeks still showed a slight gain. The samples exposed for 15 weeks were used in determining the loss at 2, 8, 15, 22, 50, and 105 days, while the percentage of loss given for the 35- and 70-day exposures was based on samples used for test at the end of 5 and 10 weeks, respectively. This was done to eliminate errors in calculating the results of subsequent tests made upon the respective residues and accounts for slight variations that may appear to indicate gains instead of losses.

As was expected, the cut-back products lost weight very rapidly. At the end of 2 days they had lost from 86 to 92 percent of their maximum loss with an average of 89 percent, and at the end of 35 days they had lost from 97 to 100 percent with an average of 99 percent. For the slow-curing products the rate of loss was much less, but was considerably more variable. In 2 days those samples that had undergone a loss had lost from 3 to 60 percent of their maximum loss with an average of 35 percent. In 15 days they had lost from 16 to 84 percent with an average of 50 percent, in 35 days from 63 to 100 percent with an average of 82 percent, and in 70 days from 74 to 100 percent with an average of 89 percent. Some idea of the relative speed of curing or volatility of the two types of material may be obtained by comparing their losses under these exposure conditions. The slow-curing materials took 70 days to lose an average of 89 percent of their volatile matter, while the cut-back materials underwent the same percentage loss in 2 days.

TABLE 5.—*Loss in thin film exposure*

Sample identification	Loss on exposure for—							
	2 days	8 days	15 days	22 days	35 days	50 days	70 days	105 days
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	−2.6	−3.6	−3.4	−3.4	−3.0	−2.7	−2.7	−0.9
2	1.9	4.3	5.7	7.6	9.5	10.3	10.2	12.4
3	−.2	2.0	2.9	4.7	6.6	8.0	8.0	9.4
4		1.5	1.7	3.2	5.1	4.4	5.8	5.8
5	2.6	5.4	6.5	8.2	9.5	9.8	9.9	11.5
6	−.3	1.2	2.0	4.1	5.1	6.1	8.5	8.2
7	7.8	12.9	14.6	17.7	20.2	20.0	21.0	21.5
8	−1.8				2.3		1.8	2.0
9	.3	2.4	4.0	5.3	8.1	8.2	9.6	10.7
10	11.0	14.4	14.5	15.7	16.4	16.7	16.8	17.3
11	7.8	14.7	16.4	18.2	20.4	21.0	21.6	22.3
12	4.6	8.9	9.4	11.8	13.7	13.4	13.8	15.2
13	.4	2.6	4.3	6.1	7.3	10.1	8.5	9.8
14	−1.3	.2	1.3	3.4	5.2	6.9	6.0	8.1
15	1.9	5.5	6.9	8.4	9.3	12.1	10.6	13.3
16	−3.5	−1.5	−1.0	1.8	4.6	5.7	5.7	6.7
17	8.6	12.6	14.4	15.9	18.5	18.9	18.7	19.5
18	11.5	15.7	16.5	17.4	18.2	19.2	17.7	19.0
19	1.4	5.0	6.1	8.6	10.1	12.4	12.0	13.8
20	2.3	6.8	7.8	9.8	11.7	12.6	11.5	13.6
21	−1.1	3.7	6.4	8.2	12.5	13.6	12.9	14.3
22	.6	3.4	5.1	6.7	8.5	9.8	9.1	10.5
23	1.3	3.7	4.6	6.6	8.3	10.6	13.1	11.2
24	19.4	21.2	21.5	22.0	22.2	22.2	22.5	22.5
25	20.1	21.6	21.9	22.1	22.2	22.0	22.0	22.2
26	20.5	21.6	21.8	22.1	22.4	22.1	22.1	22.0
27	26.1	27.1	27.3	27.5	27.6	27.6	28.3	27.8
28	17.7	19.6	19.9	20.0	19.9	20.1	20.0	20.1
29	19.2	20.8	21.3	21.4	21.6	21.4	21.4	21.4

LOSS IN DISTILLATION TEST MOST NEARLY APPROXIMATED LOSS IN 15 WEEKS' EXPOSURE FOR ALL TYPES OF MATERIALS

Figure 5 shows the relation between the percentage of loss upon exposure and loss in the distillation test, loss in the two oven tests, and loss in the asphaltic-residue test. Figure 5 indicates that for the slow-curing products the loss in 15 weeks' exposure was about 2½ times as great as that in the oven test on a 50-gram sample, about 1½ times as great as that in the oven test on a 20-gram sample, and about the same as the loss in the distillation test. No relationship was apparent between the loss in the exposure and asphaltic-residue tests. The loss in the latter test was, however, invariably greater, ranging from 1⅓ to 14 times the loss occurring in 15 weeks' exposure with an average of 2½ times this loss. For the cut-back products the loss in all tests was approximately the same. In all the materials studied, both in 1932 and 1933, the total loss in

TABLE 6.—*Results of tests on exposure residues*

Sample identification	5-week exposure										10-week exposure										15-week exposure									
	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 31°-37° F.	Organic matter insoluble in CS₂	Organic matter insoluble in CCl₄	Insoluble in 86° B naphtha	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 31°-37° F.	Organic matter insoluble in CS₂	Organic matter insoluble in CCl₄	Insoluble in 86° B naphtha	Loss	Float at 122° F.	Penetration: At 77° F., 100 g, 5 sec.	Penetration: At 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 centimeters per minute: At 77° F.	Ductility at 5 centimeters per minute: At 31°-37° F.	Organic matter insoluble in CS₂	Organic matter insoluble in CCl₄	Insoluble in 86° B naphtha
	Pct.	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Sec.*			*°F.*	*Cm*	*Cm*	*Pct.*	*Pct.*	*Pct.*
1	−2.6	68								15.4	2.7	110			[illegible]					20.1	−0.9		197	71	114	20.0	[illegible]		[illegible]	[illegible]
2	9.5		86	34	108	63.0	1.5	2.74	9.23	30.2	10.2		33	15	142	[illegible]	0.0	5.08	13.34	34.5	12.4		[illegible]	9	154	.3	.0	[illegible]	15.36	[illegible]
3	6.6	153			95			2.93	8.44	28.0	8.0		62	22	[illegible]	5.0	.0	4.46	11.29	31.3	9.4		49	[illegible]	[illegible]	.8	[illegible]	[illegible]	[illegible]	[illegible]
4	5.1		152	39	106	22.0	4.0	1.28	5.95	25.6	5.8		112	33	134	4.3	.0	2.46	7.41	29.3	[illegible]		[illegible]	18	[illegible]	.5	.0	[illegible]	[illegible]	[illegible]
5	9.5	200			96					25.9	9.9		97	37	118	87.0	3.8			30.5	[illegible]		52	23	135	21.0	.5		.17	35.0
6	−0.3	34								15.3	7.4	44								17.0	8.2	71							.13	18.7
7	20.2	123								21.0	21.0	[illegible]			95					22.1	21.5		195	76	[illegible]	[illegible]	[illegible]		.12	[illegible]
8[1]	2.3	163			96				.25	18.7	1.8	356	300+		129	3.5	2.3	.26	.88	22.5	2.0	1,000+	300+	[illegible]	[illegible]	3.5	[illegible]	[illegible]	1.48	[illegible]
9[2]	8.1	1,000+	300+		110			3.22	7.51	26.4	9.6	1,000+	300+	97	139	1.0	.5	5.16	10.49	30.2	10.7		199	[illegible]	[illegible]	.5	[illegible]	[illegible]	11.34	[illegible]
10	16.4		189	80	106	95.0	5.0			26.6	16.8		95	53	129	10.0	3.5			29.4	17.3		76	17	135	7.5	3.0		.24	31.2
11	20.4	131								23.8	21.6		73	35	121	17.0	1.5			29.3	22.3		[illegible]	22	130	9.0			.12	[illegible]
12	13.7	110								21.0	13.8	203			105					23.9	15.2		175	84	115	41.0	[illegible]		[illegible]	24.7
13	7.3	129								21.8	8.5		89	39	119	40.0	3.5			[illegible]	9.8		72	33	[illegible]	16.0	[illegible]		[illegible]	29.6
14	5.2	105						1.63	5.69	29.4	6.0		126	31	[illegible]	105.0	2.5	3.08	7.94	31.5	8.1		80	21	112	97.0		3.07	8.61	[illegible]
15	9.3	150								25.9	10.6		105	47	117	53.0	3.5			30.3	13.3		[illegible]	30	133	8.0	.5		.23	33.2
16	4.6	70								19.9	5.7	218			101					[illegible]	6.7		[illegible]	99	109	47.0	5.0		[illegible]	25.1
17	18.5		51	22	136	6.0	.0	1.81	7.57	30.8	18.7		36	14	[illegible]	.5	.0	3.17	9.66	36.2	19.5		29	12	168	.5	.0	3.30	9.88	35.4
18	18.2	197			93					14.8	17.7		152	43	105	110+	7.5			[illegible]	19.0		[illegible]	28	116	110+	[illegible]		.10	18.8
19	10.1		156	28	98		1.0	4.60	11.69	34.4	12.0		44	10	121	110+	.0	6.50	16.02	38.7	13.8		29	7	128	110+	.0	7.50	18.15	39.9
20	11.7	179			95					21.4	11.5		136	41	112	90.0	3.8			24.2	13.6		84	28	120	72.0	3.0		.09	27.2
21	12.5	106								18.2	12.9	170			95					22.3	14.3		166	48	103	110+	8.5		.08	23.7
22	8.5	150			87					19.1	9.1		157	42	104	110+	7.3			23.2	10.5		112	28	111	110+	5.0		.10	[illegible]
23	8.3	116							.15	24.7	13.1		27	14	147	1.0	.0	.20	2.91	32.8	11.2		49	22	129	[illegible]	.0	.28	.81	[illegible]
24	22.2		21	9	146	17.0	.0	.21	.28	32.4	22.5		12	10	161	5.5	.0	.45	.47	36.9	22.5		13	6	160	[illegible]	[illegible]	.63	.73	37.4
25	22.2		29	14	155	5.0	.0	.38	.50	31.7	22.0		25	13	158	4.8	.0	.43	.43	33.9	22.2		24	13	163	4.0	.0	.72	[illegible]	34.2
26	22.4		26	14	151	4.5	.0	.23	.20	29.0	22.1		20	13	163	3.5	.0	.35	.41	31.5	22.0		22	13	161	3.8	.0	[illegible]	.51	31.4
27	27.6		18	7	138	4.0	.0	.32	2.21	27.9	28.3		12	6	158	.0	.0	.34	2.26	30.5	27.8		14	5	153	.3	.0	.57	2.40	31.6
28	19.9		21	9	151	7.0	.0	.23	.23	28.2	20.0		16	9	163	4.5	.0	.45	.45	31.0	20.1		17	8	168	3.8	.0	.44	.52	[illegible]
29	21.6		23	13	154	7.0	.0	.39	.39	34.7	21.4		18	13	169	4.5	.0	.51	.50	27.9	21.4		17	11	172	4.0	.0	[illegible]	[illegible]	39.3

[1] The 10- and 15-week exposure residues of this sample were nonhomogeneous.

[2] None of the residues after exposure of this sample was homogeneous.

the distillation test most nearly approximated the loss in 15 weeks' exposure.

At the end of 15 weeks' exposure the surfaces of the samples varied greatly in appearance, as shown by the typical photographs in figure 4. The appearance of sample 14 was typical of samples 1, 2, 3, 4, 5, 6, 7, 9, 12, 18, 19, 20, 21, and 22. However, there were some variations in actual appearance that could not be shown in a photograph. Samples 1, 2, and 3 had mottled, slightly greasy surfaces. Samples 4, 9, and 19 had mottled, slightly greasy surfaces that were slightly iridescent. Samples 14, 21, and 22 had mottled, iridescent surfaces that were not greasy. Sample 5 had a uniformly mottled appearance neither iridescent nor greasy. Samples 6, 7, 12, 18, and 20 were smooth and glossy.

Sample 23 was mottled and slightly greasy, like samples 1, 2, and 3, but had some dull areas as shown. Sample 13, while smooth and glossy, had some dull areas as shown; sample 16 was similar although it was slightly mottled.

Samples 10, 11, and 15 were checked over most of the area of their surfaces; their condition is shown by the photograph of sample 15. The unchecked areas in samples 10 and 11 were glossy but in sample 15 the surface was neither dull nor glossy. Samples 8 and 17 had very rough surfaces, shrunken and pitted as shown by their photographs. The material in the bottom of the cracks was soft but the outer surface was very hard. The cut-back products were all very rough and wrinkled, as shown by the photographs of samples 26, 27, and 28. The material in the cracks was glossy while the outer surface was dull.

At the end of 15 weeks all of the cut-back products were exceedingly hard. As they were originally combinations of semisolid asphalt and volatile fluxes and became semisolid in the laboratory tests, it would be expected that a semisolid residue would rapidly develop upon exposure. It has been believed generally that the asphalt base used in cut-back materials is relatively resistant to changes caused by weathering and that after the cutting medium is removed the character of the material changes but little. The six cut-back materials used in this study, while losing but little weight after 2 days, were much harder and had much less ductility at the end of 5 weeks' exposure than the asphalt used as base material.

The slow-curing products varied as greatly in consistency as in the rate and amount of volatile matter given off during exposure. At the end of 5 weeks all of them were harder than the residues from the distillation and oven tests, but only 5 had a penetration at 77° F. of less than 200. The consistency varied from a float of 34 seconds at 122° F. to a penetration of 51 at 77° F. At the end of 15 weeks only 3 materials had a penetration at 77° F. of over 200 and one of these materials had disintegrated to such an extent that no true penetration test was possible. The consistency ranged from a float of 71 seconds at 122° F. to a penetration of 20 at 77° F. In the previous work, the slow-curing materials all developed residues after 15

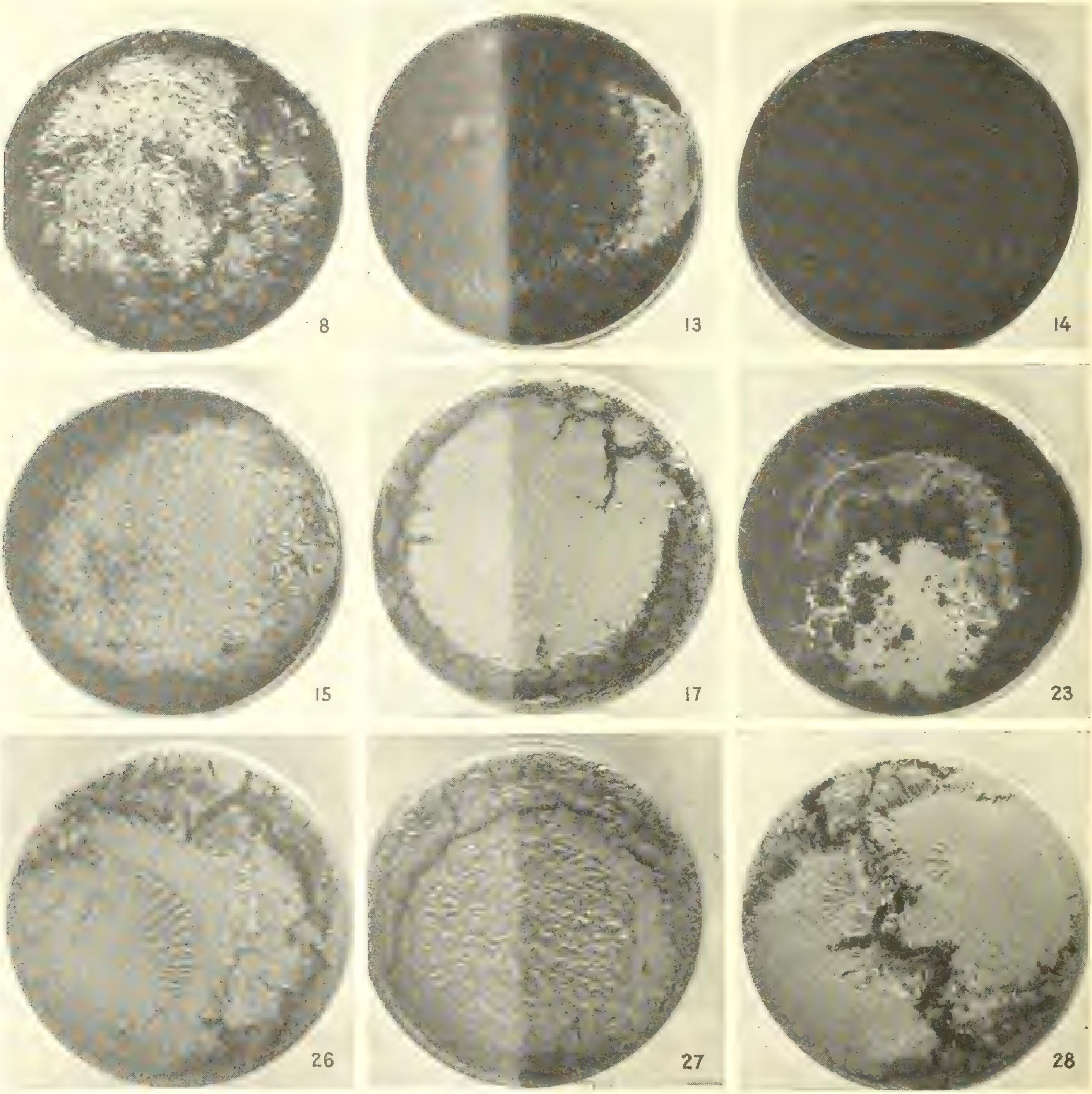

FIGURE 4.—CONDITION OF SURFACES AFTER 15 WEEKS OF EXPOSURE.

weeks that were as hard as or harder than their asphaltic residues of 100 penetration. It seems that it is impossible to predict, from the results of any of the laboratory tests, the consistency of the residues after exposure. Generally, however, those materials that took a long time to be reduced to 100 penetration in the asphaltic-residue test and those whose residues from the distillation and oven tests had a low float-test value were the softest or most fluid at the end of 15 weeks.

ASPHALTIC RESIDUES DIFFERED IN CERTAIN RESPECTS FROM RESIDUES AFTER EXPOSURE OF ABOUT THE SAME PENETRATION

A comparison of the residues after exposure and asphaltic residues is of interest. All but 5 of the asphaltic residues had ductilities at 77° F. of more than 110 centimeters and 15 had ductilities at 34°–35° F. of 3½ centimeters or more. After 15 weeks' exposure only 7 products had ductilities at 77° F. over 50 and only 4 over 110. Only 6 had ductilities at 34°–35° F. over 3½. These differences in ductilities may, in a number of instances, have been caused by differences in the consistencies of the residues after exposure and asphaltic residues.

However, in some cases one of the residues from exposure had approximately the same penetration as the asphaltic residue and the laboratory residues and residues after exposure may be compared directly. Table 7 shows the results of tests on both such residues and indicates that the two residues from the same material, although having the same consistency, varied considerably in other respects.

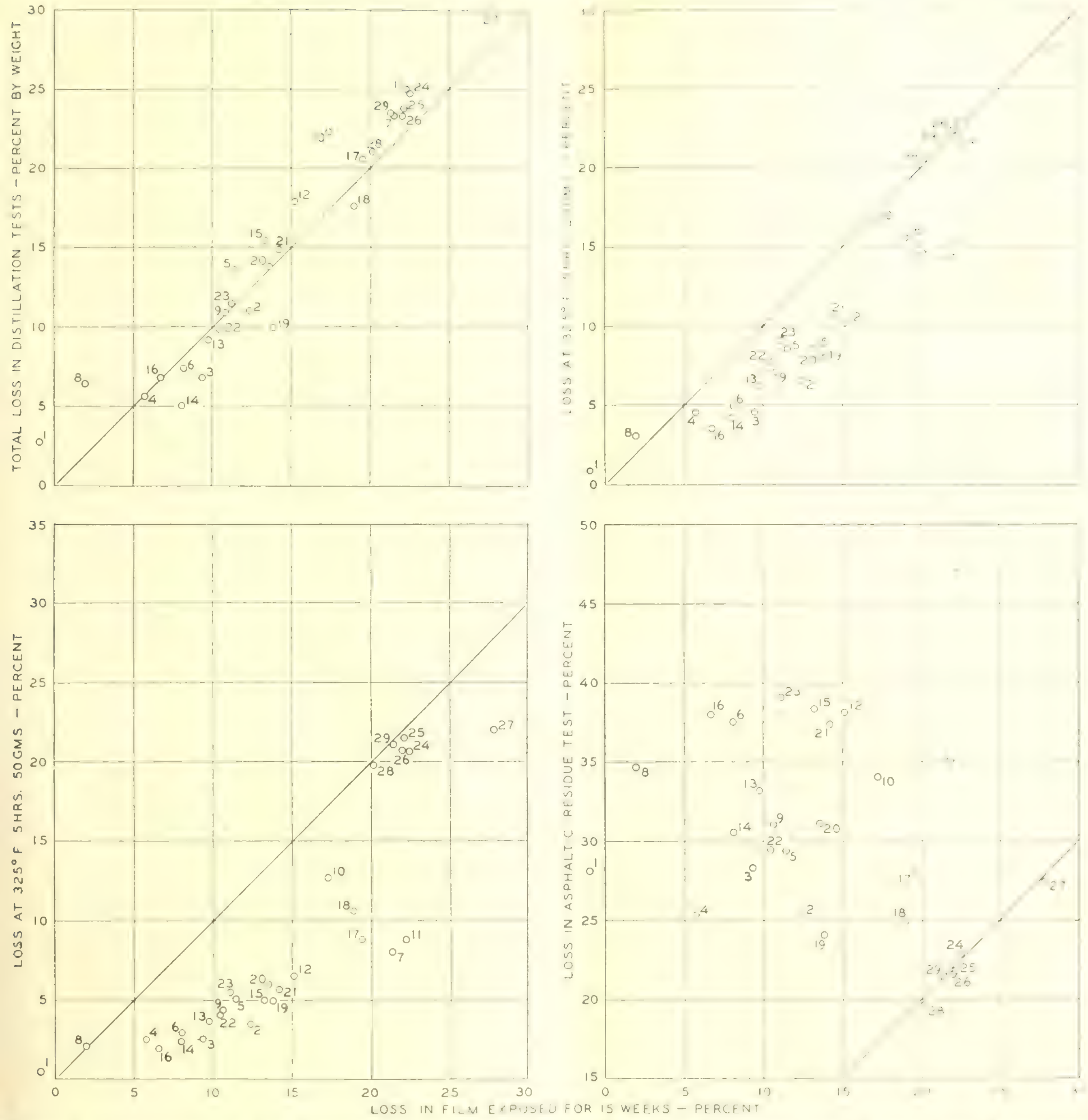

FIGURE 5.—COMPARISON OF THE PERCENTAGE OF LOSS AFTER 15 WEEKS OF EXPOSURE WITH LOSS IN THE LABORATORY EVAPORATION TESTS.

The ratio of the penetration at 77° F. to that at 32° F. was always lower for the residue from exposure. The ductility at 77° F. of the residue from exposure was less than that of the asphaltic residue in all but two cases, and for these the ductility of both residues was 110+. In five cases the ductility at 34°–35° F. of the residue from exposure was greater than that of the asphaltic residue. In every case except two the percentage of material insoluble in naphtha was greater for the residue from exposure than for the asphaltic residue. In every case where there was an appreciable amount of material insoluble in carbon tetrachloride and carbon disulphide, the percentages were much greater for the residues from exposure.

Figure 6 shows the development of free carbon, carbenes, and asphaltenes in laboratory and exposure tests for the samples that originally contained or finally developed carbenes in appreciable amounts. Samples 8, 23, and 27 developed only relatively small amounts of carbenes and the development of the insoluble constituents is shown only for sample 27. In figure 6 the volatile matter and the material insoluble in carbon disulphide, carbon tetrachloride, and 86° B. naphtha are plotted for the original materials and their residues

Table 7.—*Comparison of residues of approximately the same penetration from the asphaltic-residue test and from exposure*

Sample identification	Asphaltic residue: Penetration At 77° F., 100 g, 5 sec.	Asphaltic residue: Penetration At 32° F., 200 g, 60 sec.	Asphaltic residue: Ratio: Pen. at 77° F. / Pen. at 32° F.	Asphaltic residue: Softening point	Asphaltic residue: Ductility, 5 cm per minute At 77° F.	Asphaltic residue: Ductility, 5 cm per minute At 34°-35° F.	Asphaltic residue: Insoluble in 86° B. naphtha	Asphaltic residue: Organic matter insoluble in CCl₄	Asphaltic residue: Organic matter insoluble in CS₂	Residue from exposure: Penetration At 77° F., 100 g, 5 sec.	Residue from exposure: Penetration At 32° F., 200 g, 60 sec.	Residue from exposure: Ratio: Pen. at 77° F. / Pen. at 32° F.	Residue from exposure: Softening point	Residue from exposure: Ductility, 5 cm per minute At 77° F.	Residue from exposure: Ductility, 5 cm per minute At 34°-35° F.	Residue from exposure: Insoluble in 86° B. naphtha	Residue from exposure: Organic matter insoluble in CCl₄	Residue from exposure: Organic matter insoluble in CS₂	Time of exposure
				°F.	*Centimeters*	*Centimeters*	*Per cent*	*Per cent*	*Per cent*				°F.	*Centimeters*	*Centimeters*	*Per cent*	*Per cent*	*Per cent*	*Weeks*
2	100	15	6.7	109	110+	0.0	35.2	2.16	0.16	86	34	2.5	108	63.0	1.5	30.2	9.23	2.74	5
3	105	15	7.0	107	110+	.0	32.5	1.50	.16	62	22	2.8	127	5.0	.0	31.3	11.29	4.46	10
4	107	18	5.9	108	110+	.0	25.5	1.62	.19	112	33	3.4	134	4.3	.0	29.3	7.41	2.46	10
5	105	28	3.8	113	110+	4.5	24.2	.12	----	97	37	2.6	118	87.0	3.8	30.5	----	----	10
10	106	35	3.0	117	98	6.0	25.6	.12	----	95	53	1.8	129	10.0	3.5	29.4	----	----	10
11	84	21	4.0	113	110+	.1	21.1	.03	----	73	35	2.1	121	17.0	1.5	29.3	----	----	10
13	93	27	3.4	115	110+	1.0	22.7	.09	----	89	39	2.3	119	40.0	3.5	27.3	----	----	10
14	93	13	7.2	110	110+	.0	31.1	.72	.16	80	21	3.8	112	97.0	.0	33.4	8.61	3.07	15
15	103	25	4.1	115	110+	4.5	23.1	.03	----	105	47	2.2	117	53.0	3.5	30.3	----	----	10
18	88	27	3.3	120	110+	4.8	18.5	.15	----	93	28	3.3	116	110+	4.3	18.8	.10	----	15
20	102	21	4.9	114	110+	.8	19.5	.04	----	84	28	3.0	120	72.0	3.0	27.2	.09	----	15
22	113	23	4.9	109	110+	.0	14.5	.05	----	112	28	4.0	111	110+	5.0	24.2	.10	----	15

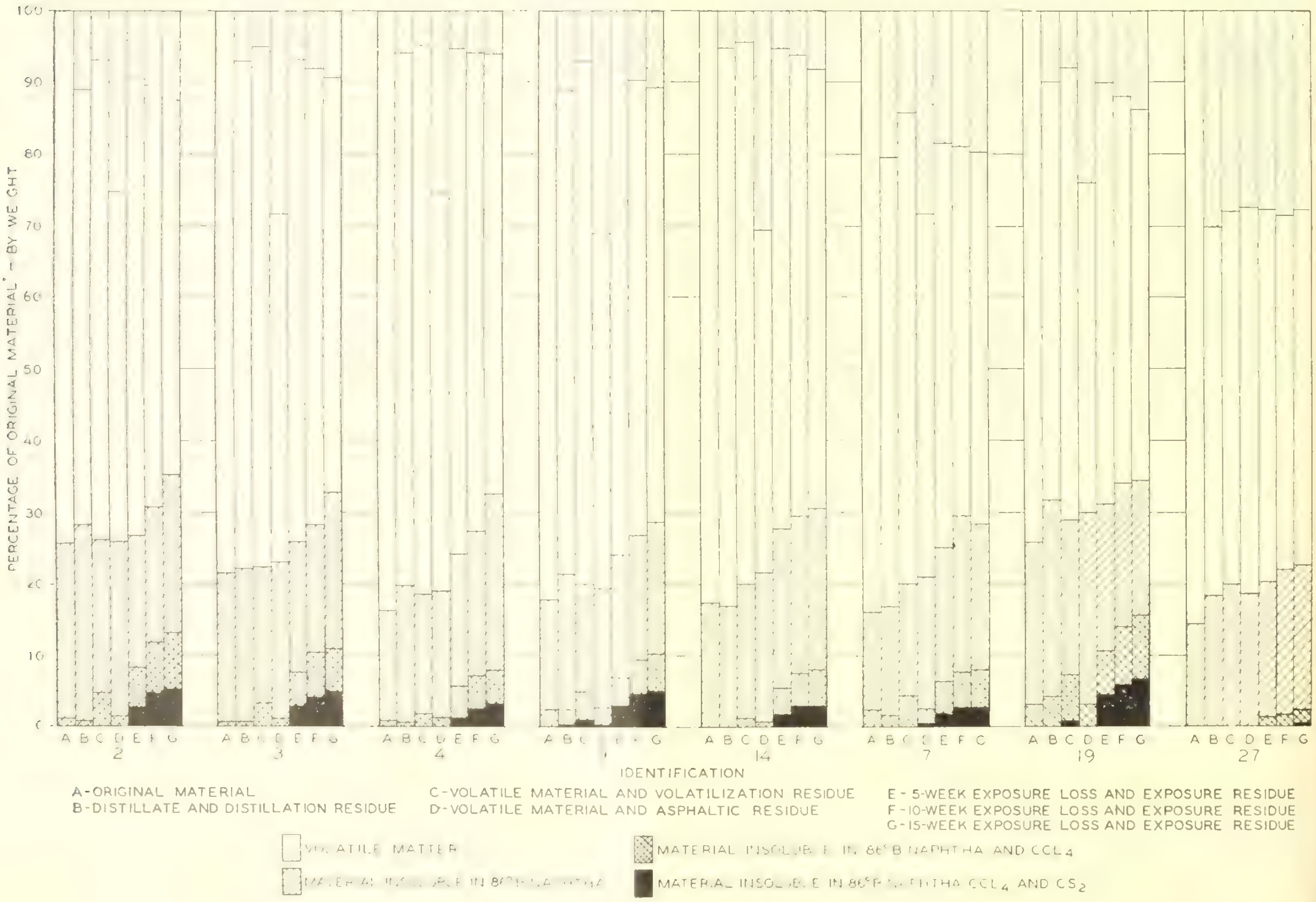

Figure 6.—Composition of Selected Materials and Their Residues as Determined by Solubility Tests.

All percentages are expressed in terms of the weight of the original material.

The solid portion in each vertical column represents free carbon or material insoluble in carbon disulphide. The remainder represents bitumen or material soluble in carbon disulphide. The double cross-hatched portion represents carbenes or bitumen insoluble in carbon tetrachloride, and the single and double cross-hatched portions together represent asphaltenes or bitumen insoluble in 86° B. naphtha. The remainder of the column represents material soluble in 86° B. naphtha that, in the original material, includes the more volatile hydrocarbons vaporized and lost under test conditions, as shown by the dotted area. The materials soluble in 86° B. naphtha have been termed "malthenes" by Richardson.[3] This designation, however, has not been generally accepted in the United States.

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[3] Clifford Richardson, The Modern Asphalt Pavement, p. 544 (2d ed.).

As shown by figure 6, the material insoluble in naphtha included carbenes and free carbon; in fact, in the residue from 15 weeks' exposure of sample 19 the material insoluble in naphtha contained 19 percent free carbon and 27 percent carbenes. The term asphaltenes also includes carbenes. Nellensteyn [4] has stated that asphaltenes, carbenes, and free carbon all consist of the same matter, that is, dispersed carbon in decreasing states of protection. The so-called "protective bodies" he designates as "micelles." He states that when extracted asphaltenes are heated at a temperature of 527° F. they will be changed largely to free carbon, but a normal asphaltic material can be heated at 662° F. for a long period with little production of free carbon. The reason for this is that in normal asphalts the amount of protective bodies, or micelles, is such that the decomposition of part of them influences their protective qualities only slightly. Marcusson [5] states that the material soluble in 86° B. naphtha (malthenes) is composed essentially of oily constituents and asphaltic resins. As the time of exposure increased, the percentage of asphaltenes, carbenes, and free carbon increased while the percentage of malthenes decreased.

In the 1932 investigation only those materials that had high specific gravities and initially contained some material insoluble in carbon disulphide with appreciable amounts insoluble in carbon tetrachloride developed carbenes either in laboratory or exposure tests. In the present study some of the materials such as samples 14 and 27, that originally had high solubilities in carbon disulphide and carbon tetrachloride, developed carbenes even during some of the laboratory tests. In those materials in which carbenes and free carbon were developed, it may be considered that the amount or the protective quality of the micelles was insufficient to prevent carbonization.

All of the rapid-curing products at the end of 15 weeks had developed residues containing about 0.5 percent of material insoluble in carbon disulphide and carbon tetrachloride. For all materials the solubility in carbon disulphide was almost the same as the solubility in carbon tetrachloride, indicating the almost complete absence of carbenes.

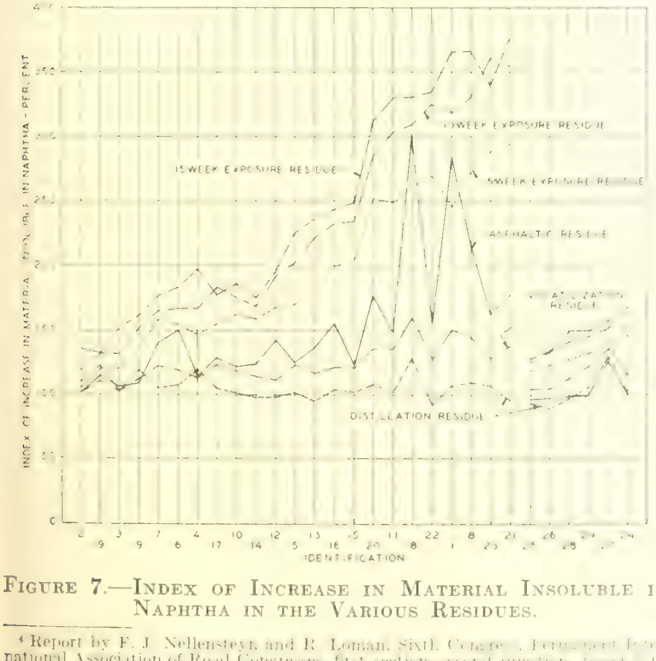

FIGURE 7.—INDEX OF INCREASE IN MATERIAL INSOLUBLE IN NAPHTHA IN THE VARIOUS RESIDUES.

MATERIAL INSOLUBLE IN NAPHTHA DEVELOPED MOST UNDER EXPOSURE AND LEAST IN THE DISTILLATION TEST

In figure 6, where all the percentages are expressed in terms of the weight of the original material, if the percentage of material insoluble in naphtha in any residue is divided by the percentage of material insoluble in naphtha in the original material and multiplied by 100, the result is the index of increase in material insoluble in naphtha. An index of 100 therefore indicates no change in the amount of material insoluble in naphtha. This index for all the samples is plotted in figure 7 and shows that generally there was an increase in material insoluble in naphtha during the various tests. Generally, this index was least for the distillation test and greatest for the 15-week exposure test. In the distillation test it ranged from 88 to 129.

While inaccuracies in testing may account for indexes of less than 100 in the distillation residues, it is possible for indexes actually to be below 100. Several samples of very viscous, slow-curing asphaltic material, really semisolid asphalts, were recently subjected to the distillation test. The materials did not yield any distillate but there was considerable loss on cooling. Nevertheless, the residues were softer than the original materials and contained less material insoluble in naphtha.

In the oven-loss test on 20-gram samples the index varied from 101 to 161 and in the asphaltic residue test it varied from 96 to 302. In the case of the asphaltic residue the index was low when the time of reduction was low, and for the cut-back materials the asphaltic residue test was the least severe of all tests, although there is not much difference between this and the distillation test. The index was high when the time of reduction was high, as indicated by sample 18 which took 420 minutes to come to 100 penetration and had an index of 302, and by sample 1 which took 280 minutes and had an index of 284. The index varied from 105 to 294 for 5 weeks' exposure, from 119 to 361 for 10 weeks' exposure, and from 133 to 376 for 15 weeks' exposure. Except for four samples, the index of increase was greater for 5 weeks' exposure than for any of the laboratory tests. In the exposure tests, products originally containing the highest percentages of material insoluble in naphtha generally had the smallest indexes of increase.

OLIENSIS TEST INVESTIGATED

An interesting development in the study of asphaltic materials is the test for determining heterogeneity. This test has been called the Oliensis or spot test. The method of making the test and the interpretation of the results were outlined in a paper read before the 1933 meeting of the American Society for Testing Materials. In making this test on the original material, one part by volume of the asphaltic material was treated with 5.1 parts by volume of a special naphtha at such a temperature that solution or dispersion was complete in 6 to 8 minutes. After cooling to room temperature and adding fresh naphtha to replace any losses, a drop of the mixture was allowed to drop on a filter paper (J. H. Munktells, No. OO). The appearance of the resulting stain varied from a uniformly colored spot, indicating complete dispersion, to stains in which the center was black and rough and surrounded by a lighter-colored ring. When an entirely uniform stain was obtained another test was made after the mixture had stood for 24 hours. The appearance of the central spot was taken as an indication of the degree of heterogeneity, and those materials that gave a uniform stain after standing 24 hours were considered as homogeneous.

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[4] Report by F. J. Nellensteyn and R. Loman, Sixth Congress, Permanent International Association of Road Congresses, first section, second question, [illegible]

[5] See Asphalts and Allied Substances by Herbert Abraham, third edition, [illegible]

The test is presumed to give an insight into the conditions of manufacture. The types of asphaltic products that should be expected to appear homogeneous are as follows:

1. Steam-refined residuals known to have been refined without serious cracking.
2. The bitumen of certain native asphalts.
3. Some types of slightly oxidized residuals from asphaltic-base crude oils.

The materials that should be expected to appear heterogeneous are:

1. Steam-refined residuals that have been overheated during the refining process.
2. Cracking-coil residuals.
3. Highly blown residuals

The test was initially developed and used to determine whether or not petroleum asphalts had been subjected to higher temperatures than usually occur in steam refining. It has been used by some States as an identification test for the control of liquid asphaltic materials. Recently the test procedure has been standardized by a group of Middle-Western States. In applying the test to slow-curing materials they state that if the material has less than 15 percent of distillate by volume at 680° F., the test may be made on the original material. For all other materials of the slow-, medium-, or rapid-curing classes the test shall be made on the distillation residue. The presence of the volatile distillate in these types of materials was thought to interfere with the sensitivity of the test. It will be noted that in the case of the slow-curing materials investigated the test may be run on 18 samples as received, since in only 5 cases was the percentage of distillate by volume at 680° F. more than 15 percent.

The identification of the character of the manufacturing process was the main object of this test, and for this purpose it should be made only on the finished products as they leave the refinery and not after they have been subjected to various laboratory heat tests. However, in order to determine if the character of the materials underwent a change during the laboratory tests and under exposure, the residue from the distillation test, the 20-gram oven-loss test, and the asphaltic-residue test, as well as the residues from the 5-week and 15-week exposures were subjected to the Oliensis test.

TABLE 8.—*Ratio of naphtha to asphaltic material in Oliensis test*

Sample identification	Original material[1] (by weight)	Distillation residue		20-gram loss residue (by weight)	Asphaltic residue (by weight)	Residue from exposure for—	
		By weight	By volume			5 weeks (by weight)	15 weeks (by weight)
1	4.10	4.21	----	4.12	5.69	4.10	4.10
2	3.74	4.20	5.83	4.01	5.00	4.13	4.27
3	3.74	4.01	5.51	3.92	5.22	4.00	4.13
4	3.79	4.01	----	3.96	5.07	3.99	4.02
5	3.96	4.58	6.04	4.33	5.61	4.37	4.47
6	4.06	4.38	----	4.26	6.49	4.35	4.42
7	4.11	5.37	6.90	4.30	6.37	5.15	5.24
8	4.13	4.51	----	4.27	6.32	4.20	4.22
9	3.83	4.29	5.86	4.11	5.55	4.16	4.28
10	4.10	5.28	6.84	4.92	6.22	4.90	4.96
11	3.91	5.22	6.94	4.61	7.35	4.91	5.03
12	4.10	4.99	6.38	4.57	6.68	4.75	4.84
13	3.91	4.31	5.68	4.17	5.86	4.21	4.33
14	3.73	3.92	----	3.89	5.36	3.93	4.06
15	4.03	4.77	6.18	4.42	6.54	4.44	4.65
16	4.07	4.37	----	4.22	6.56	4.26	4.37
17	3.83	4.82	6.80	4.52	5.18	4.70	4.76
18	4.13	5.02	6.42	4.95	5.52	5.07	5.10
19	3.65	4.05	5.76	3.97	4.73	4.06	4.23
20	4.12	4.78	6.05	4.53	5.95	4.65	4.76
21	4.06	4.77	6.07	4.55	6.52	4.64	4.74
22	4.05	4.48	5.70	4.38	5.76	4.42	4.52
23	3.90	4.41	5.86	4.29	6.44	4.25	4.40
24	4.06	5.40	7.40	5.22	5.27	5.22	5.24
25	4.17	5.48	7.24	5.38	5.34	5.36	5.36
26	4.16	5.44	7.14	5.36	5.31	5.37	5.34
27	3.99	5.72	7.98	5.54	5.50	5.52	5.54
28	4.14	5.24	6.90	5.20	5.15	5.17	5.18
29	4.11	5.38	7.29	5.24	5.24	5.24	5.24

[1] All original material 5.1 naphtha to 1 of sample by volume.

TABLE 9.—*Character of original materials and residues as determined by the Oliensis test* [1]

Sample identification	Original material	Distillation residue	20-gram loss residue	Asphaltic residue	5-week exposure residue	15-week exposure residue
1	H	H	H	H	H	H
2	H	H	H	H	H	H
3	H	H	H	H	H	H
4	H	H	H	H	H	H
5	H	H	H	H	H	H
6	O	O	O	O	SH	H
7	SH	O	O	O	H	H
8	O	SH	SH	SH	H	H
9	H	H	H	H	H	H
10	O	SH	SH	O	H	H
11	H	H	H	H	H	H
12	O	O	SH	SH	H	H
13	H	H	H	H	H	H
14	H	H	H	H	H	H
15	O	SH	SH	SH	H	H
16	SH	SH	SH	H	H	H
17	H	H	H	H	H	H
18	SH	SH	O	O	SH	H
19	H	H	H	H	H	H
20	SH	SH	O	O	H	H
21	O	O	O	O	H	H
22	O	O	O	O	H	H
23	H	H	H	H	H	H
24	H	H	H	H	H	H
25	O	O	O	O	SH	SH
26	O	SH	SH	O	SH	SH
27	H	H	H	H	H	H
28	O	O	O	O	SH	SH
29	H	H	H	H	H	H

[1] H = Heterogeneous; O = Homogeneous; SH = Slightly heterogeneous.

For the original materials 5.1 parts of naphtha by volume were mixed with 1 part of asphaltic material. For the various residues the volume of naphtha was kept constant and the weight of a unit volume of the original material minus the weight of volatile matter that occurred in producing the residue was used. Table 8 shows the ratio of naphtha to asphaltic material used for each sample. Only in the case of the asphaltic residue of sample 11 did the ratio of naphtha to asphaltic material exceed 7 to 1 by weight, the proportion that was being used by one State at the time these tests were made. It is thought that the variations in proportions of naphtha used in this work were not sufficiently wide to affect the character of the stains obtained. Table 9 gives a classification of the stains and figures 8, 9, and 10 show stains typical of those obtained with the various samples and their residues.

Since the results of the tests were based upon the appearance of the stain as interpreted by the observer, it is difficult if not impossible to distinguish between border-line materials or to express clearly the apparent degree of heterogeneity that may be indicated by the varying degrees of nonuniformity in the stain. The classification given in table 8 should be understood to mean that, in the judgment of the observers, the materials and their residues gave stains that appeared either entirely uniform throughout or were only slightly non-

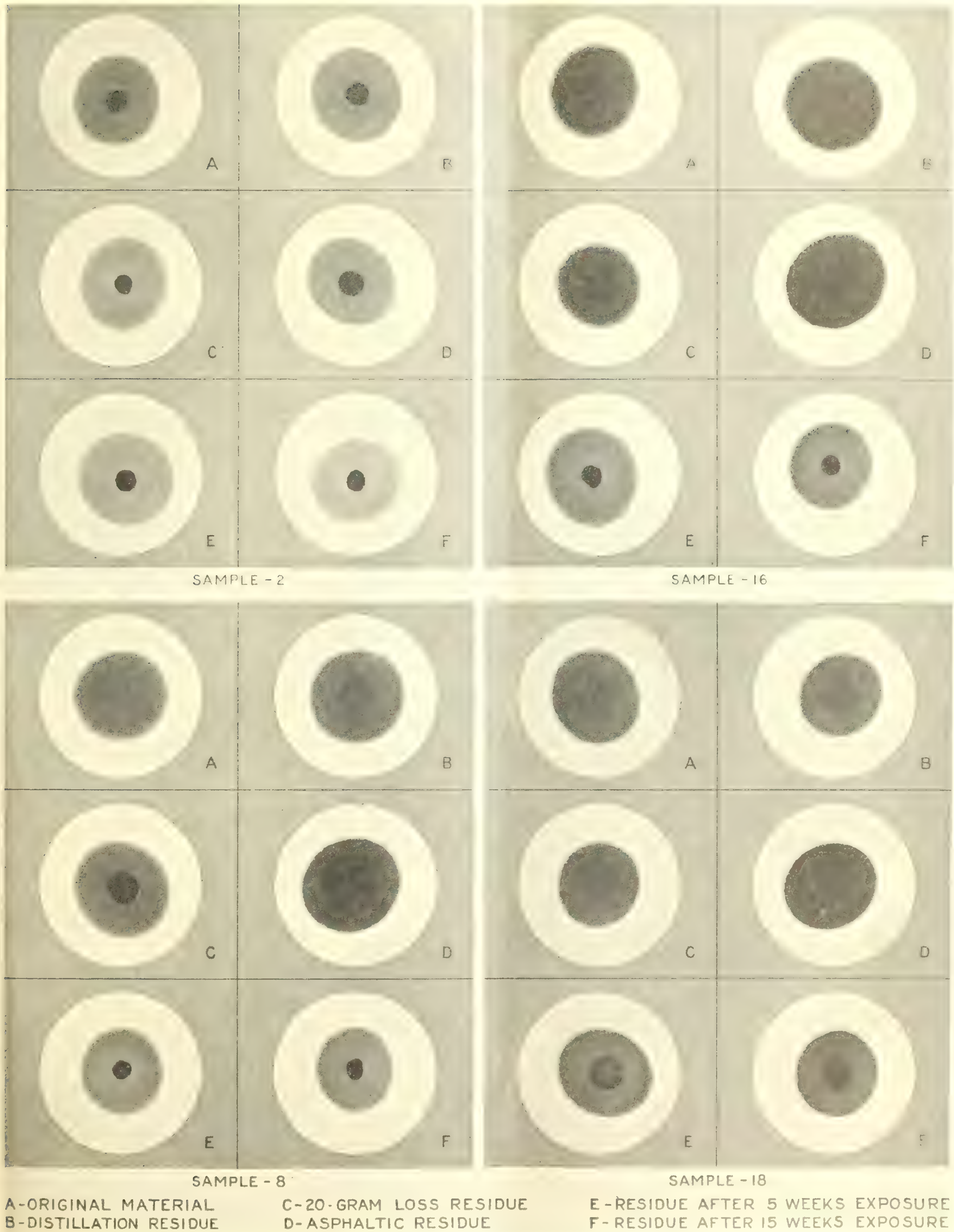

Figure 8.—Typical Oliensis Stains.

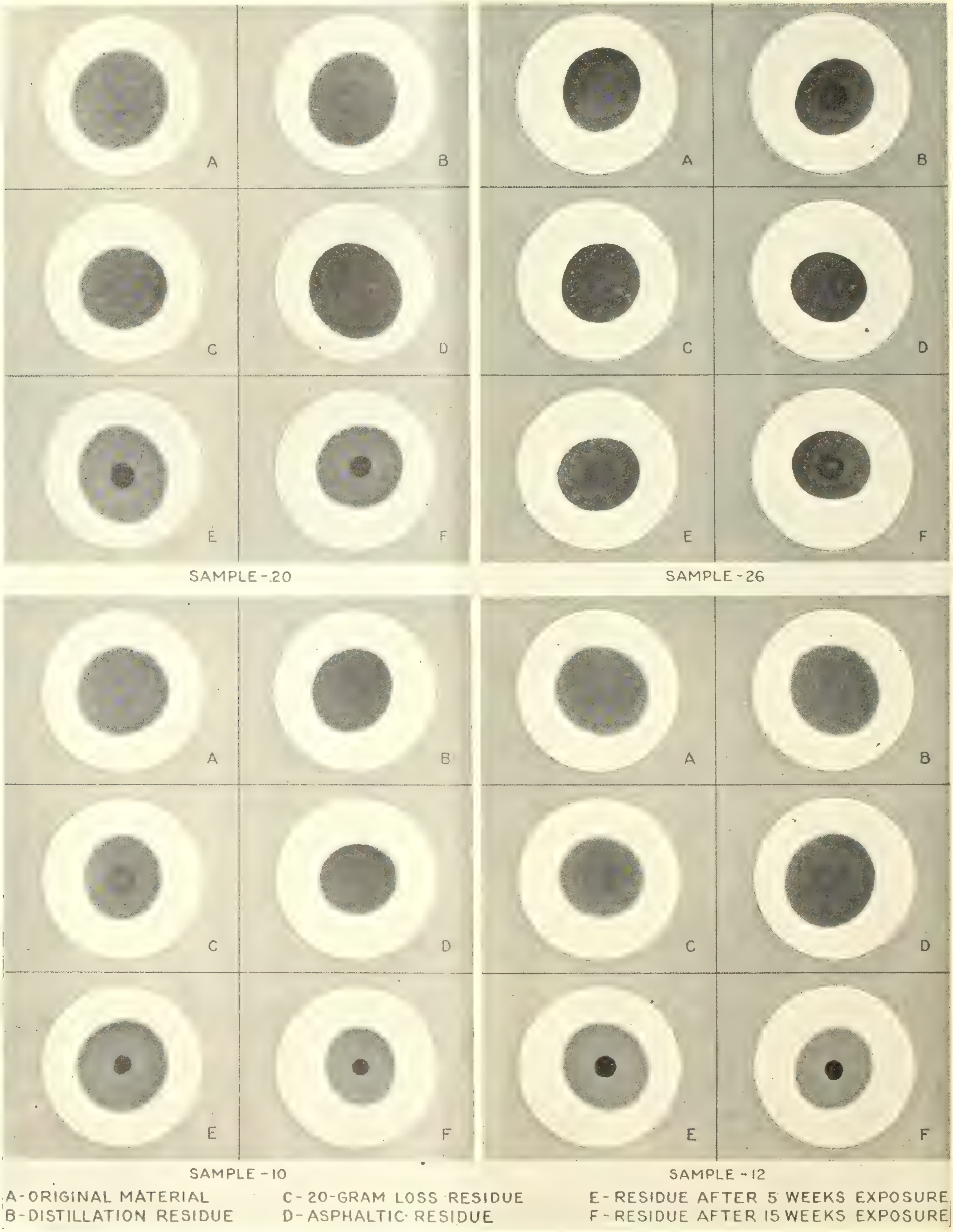

FIGURE 9.—TYPICAL OLIENSIS STAINS.

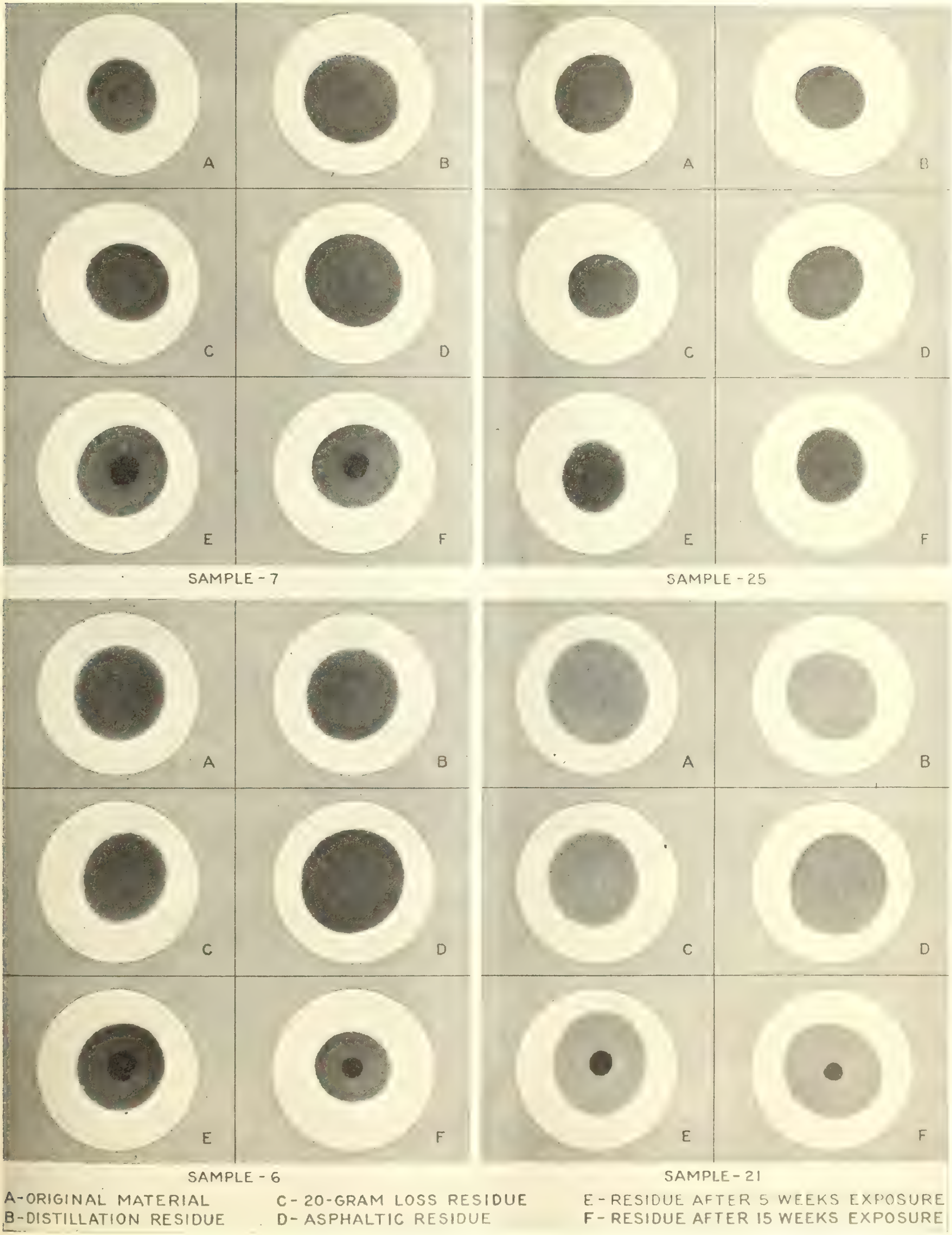

Figure 10.—Typical Oliensis Stains.

uniform, having a slightly darker, more-pronounced center, or else they had a definite dark to black center surrounded by a uniformly lighter-colored stain and were consequently classified as homogeneous, slightly heterogeneous, and heterogeneous, respectively. No attempt was made to indicate the extent or degree of heterogeneity other than to classify as slightly heterogeneous those materials and residues giving stains only slightly nonuniform.

ALL EXPOSURE RESIDUES FOUND TO BE HETEROGENEOUS

A study of the results of the Oliensis test shows that of the 29 materials, 10 were homogeneous, 4 slightly heterogeneous, and 15 definitely heterogeneous in their original state. All the residues from exposure were heterogeneous or slightly heterogeneous. Of the 10 materials appearing homogeneous in their original state, 5 developed homogeneous residues in all 3 laboratory loss tests, 2 developed slightly heterogeneous residues in all 3 tests, 2 developed slightly heterogeneous residues in the oven test and distillation test but not in the asphaltic-residue test, and 1 developed slightly heterogeneous residues in the oven test, and asphaltic-residue tests but not in the distillation test.

Of the 4 materials appearing slightly heterogeneous in their original state, 1 developed homogeneous residues in all 3 laboratory tests, 2 developed homogeneous residues in the asphaltic-residue and loss tests but remained heterogeneous in the distillation test, and one material remained heterogeneous in all tests. The 15 materials that appeared heterogeneous in their original state all developed heterogeneous residues.

A comparison of these materials according to the character of the stains produced in the laboratory and their behavior under laboratory and exposure conditions may be of interest. Nine of the materials, samples 2, 3, 4, 9, 14, 17, 19, 23, and 27, were heterogeneous originally and had heterogeneous residues. The photograph of sample 2 in figure 8 is typical. All of the above samples, except 23 and 27, showed micropscopic flecks as shown in figure 2 when examined under the microscope. All except samples 14 23, and 27 had appreciable amounts of material insoluble in carbon tetrachloride in the original sample. Samples 14, 23, and 27 developed carbenes at the end of 15 weeks of exposure and the other samples showed an increase in carbenes and free carbon.

All of the nine samples, except sample 23, had high percentages of material insoluble in naphtha. All had specific gravities greater than 1.01, except sample 27. This material has a very high specific gravity for a fluid cut-back and its behavior and characteristics place it in this group having high specific gravities. The asphaltic residues of the 9 samples showed the effect of changes in temperature, having low penetration at 32° F. and no ductility at 34°–35° F., although all had ductilities of over 110 at 77° F.

After 15 weeks' exposure all the materials were very hard, except sample 9, which, at the end of 5 weeks, had separated into two parts, one hard and brittle, the other soft and oily. It was impossible to flux these two parts so that, while having a float at 122° F. of over 1,000 seconds at the end of 5 weeks, it was impossible to get a penetration until the end of 15 weeks. When running the softening point test on the residues of this sample, after exposure, the material did not flow slowly to the bottom but dropped immediately at the temperature reported in table 5. Ductility tests were made on this sample but the results are unimportant as no true ductility value was obtained. The residues after 15 weeks' exposure of samples 2, 3, 4, 17, 23, and 27 had very low ductility at 77° F. but samples 14 and 19 had ductilities at 77° F. of 97 and 110+, respectively. None of the residues had any ductility at 34°–35° F.

Three of the materials, 5, 11, and 13, gave Oliensis stains identical with those of the preceding samples. They did not, however, have as high specific gravities, were clear in the microscopic test, and did not, even at the end of 15 weeks, develop any carbenes. Their asphaltic residues had some ductility at 34°–35° F. and, at the end of 15 weeks, while having low ductility at 77° F., samples 5 and 13 had some ductility at 34°–35° F.

The remaining 17 materials all had low specific gravities, were clear in the microscopic test, did not have carbenes, and, with 1 exception, did not develop them. They showed various types of stains in the Oliensis test although all were heterogeneous at the end of 5 weeks. Their asphaltic residues varied in ductility and effect produced by changes in temperature as did their residues after exposure.

The stains of samples 1, 24, and 29, while resulting in photographs similar to those of the high-gravity materials, did not have the nuclei as raised or as rough as the stains of the materials with high specific gravities. The producers of the cut-back asphalt designated as sample 24 stated that their plant had no cracking equipment. This material, therefore, had evidently become heterogeneous in the refining process because of overheating, since the residue obtained in laboratory tests had good ductility, indicating that it had not been overblown. Sample 29 likewise was a cut-back asphalt with a ductile base. Sample 16 was slightly heterogeneous originally, produced slightly heterogeneous residues by distillation and volatilization, and produced a heterogeneous asphaltic residue. The asphaltic residues of these four samples were not especially affected by temperature change, having some ductility at 34°–35° F., although the asphaltic residues of samples 1 and 16 had comparatively low ductilities at 77° F. The residues of samples 1 and 16 after exposure had low ductility at 77° F. Those of samples 24 and 29 (cut-back asphalts) were very hard and consequently had very low ductility.

OLIENSIS TEST MORE SENSITIVE THAN MICROSCOPIC TEST IN DETECTING OVERHEATED MATERIALS

Samples 8 and 15 were homogeneous but all of their residues from laboratory tests were slightly heterogeneous. The asphaltic residue of sample 8 had relatively low ductility at 77° F. but that of sample 15 had good ductility. Both asphaltic residues had good ductilities at 34°–35° F. The residue of sample 15 after exposure had low ductility at 77° F. Sample 8, the only material of low specific gravity to develop carbenes, separted in the exposure test in the same manner as sample 9.

Samples 18 and 20 were both slightly heterogeneous but their asphaltic and loss-test residues were homogeneous. Their asphaltic residues and their residues after exposure had good ductility at 77° F. Although the asphaltic residue of sample 20 had a ductility of only three-fourths centimeter at 34°–35° F., the ductility of its residue after exposure, as well as the ductility of the two residues of sample 18, was good at 34°–35° F. Sample 18 developed a residue at the end of 5 weeks' exposure that was the least heterogeneous of any of the residues from the slow-curing materials.

Samples 10 and 26 and their asphaltic residues were homogeneous. The asphaltic residues of both samples had good ductility at 77° F. and 34°–35° F. At the end of 15 weeks, sample 10 had low ductility at 77° F. but good ductility at 34°–35° F., while sample 26, a cut-back asphalt, was extremely hard and nonductile.

Sample 12 was homogeneous as was its residue after distillation. Its asphaltic residue had good ductility at 77° F. and 34°–35° F. and the residue after exposure had fair ductility at 77° F. and good ductility at 34°–35° F.

Sample 7 was slightly heterogeneous but all of its residues from laboratory tests were homogeneous. Its asphaltic residue was ductile at 77° F. but only slightly so at 34°–35° F. and its residue after 15 weeks of exposure had good ductility at 77° F. and at 34°–35° F.

Samples 6, 21, 22, 25, and 28 were homogeneous with homogeneous residues from laboratory tests. All of their asphaltic residues had good ductility at 77° F. and all except those of samples 21 and 22, the California residuals, had good ductility at 34°–35° F. At the end of 15 weeks, sample 6 was still fluid, while the cut-back asphalt samples 25 and 28 were very hard and nonductile. Samples 21 and 22 had good ductility at 77° F. and at 34°–35° F. although their asphaltic residues were nonductile at 34°–35° F.

It is readily apparent that the laboratory tests did not produce residues that gave stains in the Oliensis test radically different from the stains of the original materials. The behavior of the residues from exposure showed, as did the other tests, that outdoor exposure alters asphaltic materials far more than any of the laboratory heat tests. This was strikingly shown by the decidedly heterogeneous stains obtained with the residues from exposure, especially in the case of the materials originally homogeneous. It is not believed, however, that it is possible to predict the physical and chemical characteristics of the material after exposure from the results of the Oliensis test, whether made on the original material, the residues from laboratory tests or both. Residues having what are believed to be desirable qualities were obtained from both homogeneous and heterogeneous materials, although heterogeneous materials undoubtedly have a more pronounced tendency to carbonize and their slow-curing products generally develop a less-ductile residue.

For detection of materials that have been inadvertently or intentionally subjected to too high a temperature during the refining process, the Oliensis test seems to be more sensitive than the microscopic test. All of the materials that had the characteristics of overheated or cracked materials were heterogeneous in the Oliensis test but only seven of them showed microscopic flecks.

HUBBARD-FIELD STABILITY TEST USED TO MEASURE BONDING STRENGTH AND DEVELOPMENT OF BONDING STRENGTH UPON EXPOSURE

Cylinders were made according to the Hubbard-Field method and tested to determine the adhesiveness or bonding strength of the original material, the residue after distillation and the asphaltic residue, and the development of bonding strength by the original materials after exposure. The first series, for the determination of bonding strength, consisted of 3 sets of 3 cylinders each for each material. The first and second sets contained 16.6 percent by volume of the original material and distillation residues respectively mixed with 83.4 percent of a standard sand. The third set contained the same percentage of asphaltic residue by weight as was contained in the cylinders made with the original materials that gave an almost constant percentage of bitumen by volume in the cylinders of this set. All cylinders of series 1 were tested immediately for stability at 77° F.

The second series of cylinders, for determination of the development of bonding strength, likewise consisted of 3 sets of 3 cylinders using the same aggregate used in the first series and the same percentage of the original materials by volume. These three sets were placed in the exposure boxes and subjected to the same exposure conditions as the thin films. One set was removed at the end of 5, 10, and 15 weeks. The cylinders were weighed before and after exposure and the loss in weight was expressed as a percentage of the bituminous material present in the cylinder as made. After weighing, the cylinders were tested for stability at 77° F.

For comparative purposes two additional sets of cylinders were made, using as a binder the amounts of distillation residue and asphaltic residue that would have been obtained if the bitumen in the cylinders containing the original material had been subjected to the distillation or asphaltic-residue test. The aggregate used was a Potomac River sand that had been separated on standard sieves and recombined to give the following grading:

	Percent
Passing no. 10, retained on no. 20	3.7
Passing no. 20, retained on no. 30	10.3
Passing no. 30, retained on no. 40	18.1
Passing no. 40, retained on no. 50	21.3
Passing no. 50, retained on no. 80	36.6
Passing no. 80, retained on no. 100	6.1
Passing no. 100, retained on no. 200	3.2
Passing no. 200	.7

This sand had a specific gravity of 2.666 and the voids in the mineral aggregate, determined on the compacted cylinders of both series, were 38 percent for the cylinders made with the original materials, 37.4 percent for the cylinders made with the distillation residue, and 36.9 percent for the cylinders made with the asphaltic residue.

The method of mixing and molding the cylinders was the same as that used in 1932. The results of the tests on the cylinders of series 1 and 2 are given in tables 10 and 11, respectively. All results are the averages of three tests.

The results of tests on the cylinders of series 1 are shown graphically in figure 11. The stability of the cylinders at 77° F. was plotted against the Furol viscosity at 122° F., and the results of the float test at 77° F. for the cylinders made with the original materials and against the float test results at 122° F. and the penetration at 77° F. for the cylinders made with the distillation residue. Since the asphaltic residues are all of approximately the same consistency, the stabilities were plotted for each sample independently.

Figure 11 shows that although the stability of the mixtures was roughly proportional to the consistency of the contained bitumen, materials having the same consistency as measured by viscosity at 122° F., float test at 77° F. and 122° F., and penetration at 77° F. had different stabilities. This was especially noticeable

TABLE 10.—*Results of tests on series 1 cylinders*

Sample identification	Original material			Distillation residue			Asphaltic residue	
	Stability at 77° F.	Float at 77° F.	Furol viscosity at 122° F.	Stability at 77° F.	Float at 122° F.	Penetration at 77° F.	Stability at 77° F.	Penetration at 77° F.
	Pounds	*Seconds*	*Seconds*	*Pounds*	*Seconds*		*Pounds*	
1	75	100	294	125	24		2,275	96
2	125	52	303	400	60		3,975	100
3	125	56	274	200	43		3,775	105
4	150	63	404	250	45		3,600	107
5	125	36	331	325	58		2,575	105
6	75	21	345	150	21		2,325	99
7	75	9	181	375	62		2,625	92
8	100	60	277	100	27		2,100	100
9	100	33	175	200	44		3,500	86
10	75	11	197	475	87		2,425	106
11	25	4	50	175	34		3,175	84
12	100	13	182	200	38		2,450	97
13	150	41	406	200	37		2,775	93
14	125	49	278	150	36		3,675	93
15	75	21	219	175	41		2,675	103
16	75	38	217	100	25		2,225	109
17	150	20	205	1,000	110		2,700	102
18	125	9	199	400	60		1,900	100
19	175	75	320	475	57		3,775	102
20	100	46	300	350	50		2,325	104
21	75	23	293	200	41		2,375	110
22	150	60	768	325	56		2,325	113
23	75	12	123	150	27		2,700	98
24	75	14	241	3,925		76	2,950	101
25	275	31	472	3,225		77	2,825	94
26	150	35	351	3,025		84	2,725	95
27	25	3	47	3,800		87	3,850	90
28	200	19	303	3,775		65	3,725	97
29	275	17	260	3,850		72	3,650	100
30	125	39	350	3,475		81	3,000	104
31	100	37	431	2,325		205	2,950	112
32	75	25	331	1,500		298	3,075	101

TABLE 11.—*Results of tests on series 2 stability cylinders*

Sample identification	Cylinders made with the original materials							Cylinders made with distillation residue		Cylinders made with asphaltic residue	
	Stability at 77° F.				Loss of bitumen			Stability at 77° F.	Theoretical loss of bitumen	Stability at 77° F.	Theoretical loss of bitumen
	When made	In 5 weeks	In 10 weeks	In 15 weeks	In 5 weeks	In 10 weeks	In 15 weeks				
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Per cent*	*Per cent*	*Per cent*	*Lbs.*	*Per cent*	*Lbs.*	*Per cent*
1	75	300	300	425	0	3	1	125	3	1,975	28
2	125	900	1,100	1,300	7	12	12	425	11	3,575	25
3	125	750	1,000	1,150	6	10	11	250	7	3,075	28
4	150	600	750	850	3	6	6	300	6	3,150	25
5	125	675	1,025	1,275	6	11	11	475	14	2,400	29
6	75	225	250	300	4	9	9	175	7	1,975	38
7	75	425	550	600	15	20	21	425	23	2,075	35
8	100	250	300	300	3	5	6	175	6	1,750	35
9	100	550	775	800	7	12	12	325	11	3,075	31
10	75	775	950	1,250	14	18	18	550	22	2,175	34
11	25	425	500	800	18	21	22	275	25	2,450	47
12	100	350	425	550	10	14	15	275	18	2,050	38
13	150	650	700	875	6	10	10	275	9	2,350	33
14	125	650	900	1,025	4	8	8	225	5	2,900	30
15	75	475	550	600	8	12	13	300	15	2,325	38
16	75	250	325	350	4	8	9	175	7	1,875	38
17	150	950	1,000	1,200	15	19	21	1,275	21	2,325	28
18	125	825	950	1,200	16	20	20	500	18	1,750	25
19	175	1,650	2,525	3,075	7	11	11	625	10	2,825	24
20	100	725	1,000	1,250	8	12	13	350	14	2,050	31
21	75	525	700	850	8	13	14	300	15	1,950	37
22	150	775	1,075	1,400	5	9	9	350	10	2,100	29
23	75	275	550	750	7	11	11	200	12	2,175	39
24	75	4,275	4,325	5,200	20	23	22	3,650	25	2,800	23
25	275	3,700	3,750	3,850	17	19	19	3,025	24	2,650	22
26	150	3,500	3,125	3,550	21	24	23	2,800	23	2,775	22
27	25	1,450	1,500	1,650	28	30	29	2,875	30	3,600	27
28	200	4,650	4,250	4,975	16	18	18	3,400	21	3,475	20
29	275	4,400	4,100	4,825	13	16	16	3,250	24	3,400	21
30	125							3,175	26	2,700	24
31	100							2,075	20	2,675	21
32	75							1,425	22	2,775	25

in the results with the cylinders made with the asphaltic residue. Although all of these residues had approximately the same penetration, the stability of the cylinders varied from 1,900 pounds for sample 18 to 3,975 pounds for sample 2.

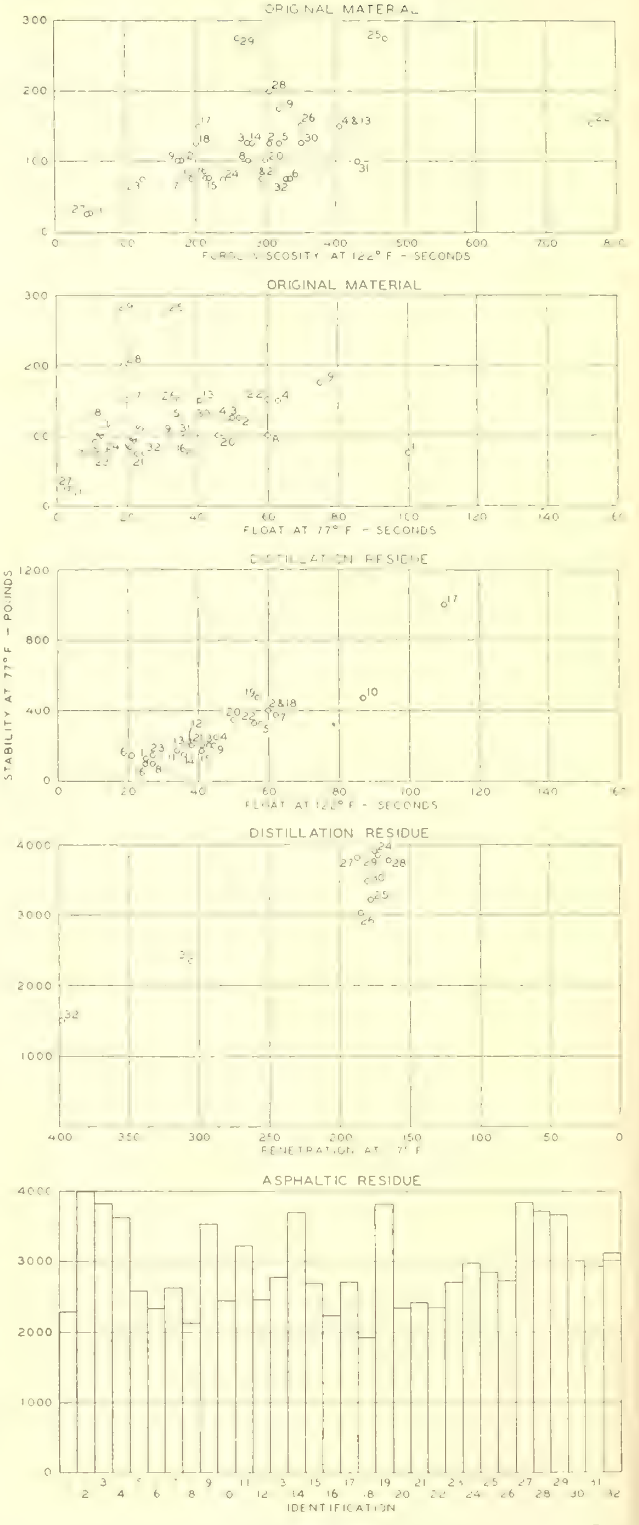

FIGURE 11.—RELATION BETWEEN THE CONSISTENCIES OF ORIGINAL MATERIALS, DISTILLATION RESIDUES, AND ASPHALTIC RESIDUES AND THE STABILITY AT 77° F. OF CYLINDERS OF SERIES 1.

It is seen that the cylinders made with the asphalti residues of samples 2, 3, 4, 9, 11, 14, and 19 all ha stabilities of over 3,000 pounds. All of these material were heterogeneous originally, all were materials o high specific gravity, and all except sample 11 containe or developed carbenes and free carbon. Sample 11 ha a relatively high specific gravity but did not develo

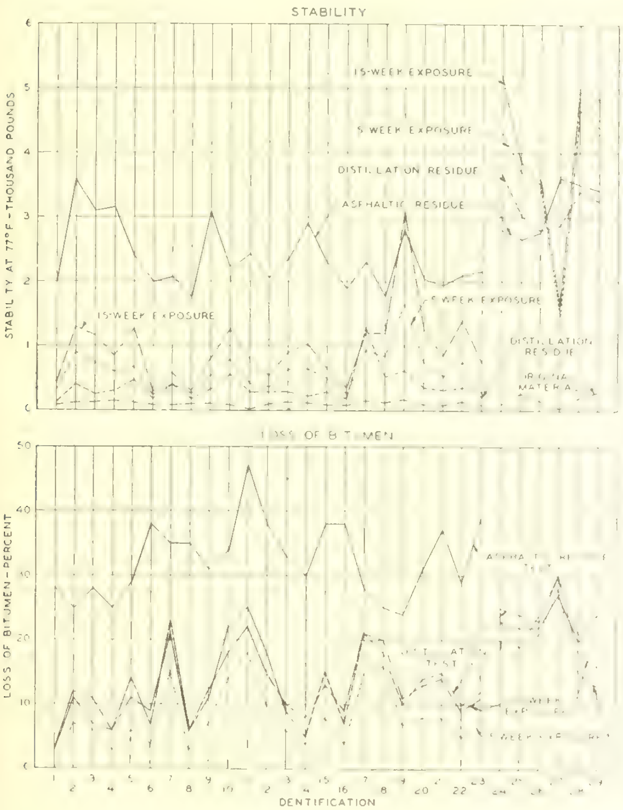

FIGURE 12.—COMPARISON OF LOSS OF BITUMEN AND STABILITY OF SERIES 2 HUBBARD-FIELD CYLINDERS.

carbenes. Samples 5, 7, 13, 15, 17, and 23 had stabilities between 2,500 and 3,000 pounds. Samples 17 and 23 were heterogeneous materials of high specific gravity that contained or developed carbenes. Samples 5 and 13 were heterogeneous materials of fairly high specific gravity but they did not develop carbenes, and samples 7 and 15 were materials of low specific gravity. All of the cut-back products had asphaltic residues giving stabilities of 2,500 pounds or over and five gave stabilities of 3,000 pounds or over.

Figure 12 shows the results of stability tests on the cylinders of series 2. The loss of bitumen in 5 and 15 weeks of exposure and the theoretical loss of bitumen in the cylinders made with the distillation and asphaltic residues were plotted for each sample. The stabilities at 77° F. for each sample were also plotted.

In this figure it is seen that, in the case of the slow-curing materials, although the loss of bitumen in the exposed cylinders was approximately the same as the loss in the distillation test, the exposed cylinders had greater stability than the cylinders made with the distillation residue except in the case of sample 17. This sample, even in 15 weeks, did not attain as high a stability as the cylinders made with the distillation residue. It is also seen that the loss in 15 weeks' exposure did not approach the loss in the asphaltic residue test and that the stability of the exposed cylinders did not approach the stability of the cylinders made with the asphaltic residue, except in the case of sample 19.

For the cut-back materials the indicated losses were probably in error due to unavoidable loss of volatile matter while mixing and molding the cylinders. The losses in 5 and 15 weeks of exposure probably should have been about the same as the losses in the distillation and asphaltic residue tests. The stabilities at 5 weeks were higher than the stabilities of cylinders made with the asphaltic and distillation residues except in the case of sample 27.

SATISFACTORY CHECKS OBTAINED WITH RESULTS OF 1932 TESTS

After the exposure tests had been started, a question was raised concerning the use of plate glass covers for the exposure cabinets because it prevented the active ultra-violet rays from acting on the materials. Fused quartz glass not being available, Vita glass, which, after a short stabilization period, is guaranteed to permanently transmit an effective volume and combination of wave lengths of active ultra-violet light, was used to determine the effect of the passage of more active light. Duplicate sets of 10 of the slow-curing materials, 2 of the rapid-curing materials, and sample 27 and 3 new medium-curing materials, samples 30, 31, and 32, were exposed under both Vita and plate glass for 5- and 10-week periods. The materials were exposed in thin films and also admixed with the standard sand in the form of Hubbard-Field cylinders.

This exposure was started August 28, 1933. During the first 5-week period the average maximum air temperature was 80° F. and the number of sunlight hours was 266. During the 10-week period the average maximum air temperature was 73° F. and the number of sunlight hours was 512. The results of the tests on the thin films are given in table 12, and those on the Hubbard-Field cylinders in table 13.

As shown by tables 6 and 12, the materials did not lose as much nor get as hard in 10 weeks as they did in the original 5 weeks of exposure. This was due to the lower air temperature and also to the fact that the sun's rays striking at an oblique angle did not cause the material to get as hot as earlier in the summer. There was little if any difference between the materials exposed under the different types of glass. The samples exposed under Vita glass had a little more material insoluble in carbon disulphide and carbon tetrachloride and generally had a little more material insoluble in naphtha. Each solubility reported was the average of 3 or more tests. The results of the stability tests do not show that there was any difference between the two types of glass. The comparative study of the effectiveness of Vita glass and plate glass as cover for the exposure of the samples did not produce differences great enough to indicate their relative efficiency for this purpose.

As stated previously, four of the samples tested in 1932 were included in the 1933 work and the results obtained, as shown in table 14, were in remarkably close agreement with the previous tests. In the case of samples 17 and 19 the residues from the 1933 exposure tests had greater percentages of free carbon and carbenes than did residues from the 1932 exposure tests.

The results of the two sets of stablity tests were not in such close agreement because the aggregate used in the 1933 tests was somewhat coarser than that used in 1932. In 1932, cylinders made with sample 17 were the only ones that, after 15 weeks' exposure, had a stability about the same as those made with the distillation residue. In 1933 the cylinders made with sample 17, after 15 weeks' exposure, had less stability than the cylinders made with the distillation residue. Cylinders of sample 19 that in 1932, after 15 weeks' exposure, had a stability approaching that of the asphaltic-residue cylinders, in 1933, after 15 weeks' exposure, had a stability higher than that of the asphaltic-residue specimens.

TABLE 12.—*Results of tests on plate and Vita glass exposure residues*

5 WEEKS' EXPOSURE

Sample identification	Plate glass										Vita glass									
	Loss	Float at 122° F.	Penetration at 77° F., 100 g, 5 sec.	Penetration at 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 cm per minute at 77° F.	Ductility at 5 cm per minute at 34°-35° F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha	Loss	Float at 122° F.	Penetration at 77° F., 100 g, 5 sec.	Penetration at 32° F., 200 g, 60 sec.	Softening point	Ductility at 5 cm per minute at 77° F.	Ductility at 5 cm per minute at 34°-35 °F.	Organic matter insoluble in CS_2	Organic matter insoluble in CCl_4	Insoluble in 86° B. naphtha
	Percent	*Seconds*			°F.	*Centimeters*	*Centimeters*	*Percent*	*Percent*	*Percent*	*Percent*	*Seconds*			°F.	*Centimeters*	*Centimeters*	*Percent*	*Percent*	*Percent*
1	−2.5	50								12.7	−3.3	46								13.4
2	6.7	113						[illegible]	6.86	29.9	4.5	92						1.22	6.85	29.2
13	4.5	61								18.4	2.2	54								17.8
14	2.2	53						[illegible]	2.68	24.8	1.6	47						.47	2.73	23.4
17	12.4	140						1.08	4.09	26.8	12.4	156						1.28	4.64	28.3
18	16.0	110								12.2	14.9	104								12.9
19	6.4	105						[illegible]	9.63	32.6	5.6	98						2.00	10.22	33.6
20	7.9	103								17.2	6.5	96								17.0
21	8.0	53								14.1	5.7	49								13.7
23	6.0	52								19.2	5.6	50								19.2
26	21.5		37	18	143	8.5	0.0	[illegible]	.33	27.3	21.5		33	16	147	10	0.0	.26	.15	27.6
27	27.1		46	14	124	17.0	.0	.19	.56	27.7	26.2		39	14	126	12	.0	.31	.64	28.0
29	18.5		40	17	141	11.0	.0			33.3	18.8		59	21	134	18	.0			31.7
30	22.6		38	16	136	18.0	.0			32.7	22.1		40	20	138	15	.0			33.5
31	17.6		61	18	124	110+	.0			29.7	17.3		52	17	126	110+	.0			30.5
32	17.7		122	24	106	110+	1			19.8	17.5		123	28	106	110+	5			20.8
10 WEEKS' EXPOSURE																				
1	−2.5	74							0.14	14.1	−3.3	56							0.22	14.6
2	7.1	152						1.42	7.77	30.2	4.1	141						1.73	8.13	30.5
13	5.1	85							.04	19.6	3.2	71							.05	20.2
14	2.2	64						.50	3.16	23.9	2.3	65						.55	3.45	24.1
17	12.9	178						1.03	5.16	28.1	12.6	297						1.24	5.39	29.1
18	16.4	144							.12	12.9	16.1	154							.16	13.9
19	7.6	145						2.42	10.42	34.3	6.9	133						2.99	10.61	33.7
20	8.3	135							.07	19.4	8.0	125							.11	19.0
21	8.7	70							.09	15.0	8.7	74							.12	15.9
23	6.1	71							.10	20.4	6.1	84							.08	21.3
26	21.4		32	17	147	[illegible]	.0	.42	.36	28.0	21.5		30	16	149	6	.0	.31	.25	28.7
27	26.4		31	13	128	[illegible]	.0	.25	.73	29.9	26.7		26	13	130	7	.0	.30	.59	31.1
29	19.3		42	17	141	13.5	.0		.22	33.4	18.9		52	19	136	16	.0		.24	33.3
30	22.6		32	14	142	8.3	.0		.23	33.9	22.3		34	15	141	11	.0		.20	35.3
31	17.8		39	14	131	33.0	.0		.13	33.7	17.3		44	15	131	32	.0		.14	33.0
32	18.1		87	22	115	63.0	.0		.17	22.2	18.0		73	17	117	65	.0		.15	23.7

CONCLUSIONS

The results of this investigation substantiate most of the conclusions arrived at in the 1932 investigation, modify two of the conclusions, and indicate some new conclusions. The conclusions substantiated are:

1. Materials of high specific gravity and their residues are, in general, more susceptible to changes in temperature than materials of low specific gravity and their residues.

2. Hardening due to causes other than loss of volatile matter, and changes in inherent characteristics that may be attributed to oxidation, polymerization, and carbonization, occur to the greatest extent upon exposure and least during distillation.

3. The development of a ductile residue either in the asphaltic-residue test or, in the case of cut-back materials, in the distillation test, does not indicate that the material will develop a ductile residue upon exposure.

4. The bonding strength of the original materials and their residues is roughly proportional to their consistencies, but materials having the same consistency as measured by the present tests do not always give the same stability. The reasons for these differences in stability cannot be determined under the present methods of testing.

The following conclusions are somewhat modified from 1932:

TABLE 13.—*Results of stability tests on cylinders exposed under plate and Vita glass*

Sample identification	Loss of bitumen				Stability at 77° F.			
	In 5 weeks		In 10 weeks		In 5 weeks		In 10 weeks	
	Plate	Vita	Plate	Vita	Plate	Vita	Plate	Vita
	Percent	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	2	1	2	1	225	250	275	375
2	8	5	8	7	850	700	850	800
13	7	4	6	5	450	450	500	425
14	4	2	4	3	475	400	500	450
17	13	12	15	13	650	700	650	700
18	18	16	18	17	500	500	525	500
19	8	6	8	8	1,075	1,000	1,250	1,275
20	8	7	8	8	550	500	500	525
21	8	7	8	8	325	350	350	350
23	5	4	6	5	225	200	250	250
26	21	21	24	23	2,775	2,650	3,550	3,500
27	28	28	30	30	1,225	1,225	1,575	1,350
29	12	12	14	13	3,775	3,725	4,600	4,575
30	23	23	24	24	2,575	2,550	2,850	3,025
31	18	19	20	20	2,325	2,375	2,725	3,125
32	18	17	19	20	1,675	1,725	2,200	2,675

5. The relative rates of volatilization of the various materials can be anticipated most readily from the distillation curves. The different classes of material may be differentiated in the loss and asphaltic-residue tests, especially if the time of reduction to 100 penetration is considered. However, sharp distinctions in initial curing properties, that may be of importance in some types of construction, can be determined only from the distillation curves.

6. Carbonization generally occurs in materials that originally contain some material insoluble in carbon disulphide and carbon tetrachloride, but some materials with exceptionally high solubility in these solvents show a tendency to carbonize under both laboratory and exposure conditions.

The following conclusions are developed upon the basis of the data collected in 1933 only:

7. The Oliensis test is more sensitive than the microscopic test in the detection of materials that have been subjected to excessively high temperatures in manufacture. However, neither test seems definitely to distinguish products that will weather badly.

8. The use of Vita glass in place of plate glass for the cover of the exposure boxes did not materially change the results. However, because of the lateness in the year when these tests were started the results are considered inconclusive.

9. If like periods of the year are used for exposure, satisfactory check tests can be obtained with the exposure assembly used in these investigations.

Many of the laboratory heat tests have been criticized as producing conditions dissimilar to and more severe than service conditions. These investigations have shown that the physical and chemical characteristics generally believed to belong to unsatisfactory materials are developed upon exposure in many products that satisfactorily withstand laboratory testing. While it is possible, by the utilization of identification tests, to restrict materials to a limited number of sources or manufacturing processes, it is impossible to predict, with any degree of accuracy, the weather-resisting properties of the material thus obtained. It is believed that efforts should be directed to the modification of some of the present laboratory heat tests so that differences in the tendency of various materials to develop unsatisfactory residues may be recognized.

Table 14.—*Comparison of 1932 and 1933 exposure tests*

TESTS ON RESIDUES AFTER EXPOSURE

Test characteristic	Sample identification							
	[illegible]		18		19		20	
	1932	1933	1932	1933	1932	1933	1932	1933
Loss in 10 weeks, percent	18.3	18.7	18.5	17.7	13.3	12.0	13.1	11.5
Penetration at 77° F.	41	[illegible]	132	152	40	44	[illegible]	136
Penetration at 32° F.	17	14	37	43	9	10	[illegible]	[illegible]
Softening point, °F.	163	170	106	105	121	121	115	112
Ductility at 77° F., centimeters	1.0	0.5	110+	110+	110+	110+	65.0	[illegible]
Ductility at 34°-35° F., centimeters	.0	.0	1.5	7.7	.0	.0	3.3	3.8
Insoluble in CS$_2$, percent	1.66	3.17		..	7.96	6.50		..
Insoluble in CCl$_4$, percent	8.27	9.66	.10	..	14.94	16.02	0	..
Insoluble in 86° B. naphtha, percent	34.8	36.2	17.6	17.3	41.1	38.7	26.8	24.2
Loss in 15 weeks, percent	19.8	19.5	18.7	19.0	13.7	13.8	13.7	[illegible]
Penetration at 77° F.	19	29	93	93	28	29	[illegible]	[illegible]
Penetration at 32° F.	12	12	29	28	8	7	24	28
Softening point, °F.	181	168	113	116	129	128	121	120
Ductility at 77° F., centimeters	0.3	0.5	86.0	115.0	110+	110+	12.0	72.0
Ductility at 34°-35° F., centimeters	.0	.0	4.0	4.5	.0	.0	1.3	3.0
Insoluble in CS$_2$, percent	2.50	3.30			6.17	7.30		
Insoluble in CCl$_4$, percent	9.11	9.88	.17	.10	15.61	18.15	.14	[illegible]
Insoluble in 86° B. naphtha, percent	37.2	35.4	19.6	18.8	38.8	39.9	28.5	[illegible]

TESTS ON HUBBARD-FIELD CYLINDERS

Test characteristic								
Loss of bitumen:								
In 5 weeks, percent	[illegible]	15	18	16	8	7	[illegible]	8
In 10 weeks, percent	18	19	[illegible]	20	10	11	12	12
In 15 weeks, percent	21	21	21	20	14	11	13	13
Stability at 77° F.:[1]								
Original cylinders, pounds	275	150	200	125	325	175	225	[illegible]
After 5 weeks' exposure, pounds	1,100	950	800	825	1,375	1,650	775	725
After 10 weeks' exposure, pounds	1,575	1,000	1,125	950	3,175	2,525	1,525	1,000
After 15 weeks' exposure, pounds	1,550	1,200	1,650	1,200	4,050	3,075	1,975	1,250
Series 2, distillation residue cylinders, pounds	1,475	1,275	750	500	800	625	500	350
Series 2, asphaltic residue cylinders, pounds	4,050	2,325	2,925	1,750	4,900	2,825	3,325	[illegible]

[1] Differences in stability probably are caused by differences in grading of the sand.

MOTOR-FUEL CONSUMPTION, 1934

[Compiled for calendar year from reports of State authorities]

State	Gross amount reported by State [1]	Exempted from payment of tax [2]		Shrinkage allowance, discounts, etc. [3]		Gross amount assessed for taxation	Subject to refund of entire tax		Amount on which tax was earned	Classification of taxed motor fuel							Percentage change in fuel consumption from previous year [6]
										By rate of tax				By use [5]			
										At full rate	At reduced rates [4]			For highway use [7]	For other uses		
		Amount	Classes of use	Percentage	Amount		Amount	Classes of use			Amount	Rate per gallon	Classes of use		Amount	Classes of use	
	1,000 gallons	*1,000 gallons*			*1,000 gallons*	*1,000 gallons*	*1,000 gallons*		*1,000 gallons*	*1,000 gallons*	*1,000 gallons*	*Cents*		*1,000 gallons*	*1,000 gallons*		
Alabama	154,977					154,977			154,977	154,977							15.8
Arizona	*75,502	3,944	F	1	713	70,845	10,280	NH, E	60,565	60,565				60,565			13.0
Arkansas	*134,249	3,444	F, E	1	1,276	129,529	3,953	NH, C	125,576	108,414	17,162	6, 5, 4, 2	(8)	[9] 119,680	[9] 5,896	NH	4.3
California	1,356,386	22,361	F	1	13,340	1,320,685	122,030	NH	1,198,655	1,198,655				1,198,655			2.1
Colorado	*172,672	2,016	F	2	3,353	167,303	24,013	NH, D, E	143,290	74,381	68,909	4	(9)	143,290			7.6
Connecticut	*308,259	50,777	F, E	1	2,549	254,933	6,275	NH	248,658	248,658				248,658			3.4
Delaware	41,556					41,556	2,042	NH	39,514	39,514				39,514			7.2
Florida	246,387	7,564	F, P	(11)	3,125	235,698			235,698	235,698							[illegible]
Georgia	243,823	2,203	F	(11)	2,185	239,435			239,435	239,435							13.7
Idaho	65,828	2,314	F			63,514	5,961	NH	57,553	57,300	253	2	AV	57,300	253	AV	[illegible]
Illinois	1,025,751					1,025,751	54,877	NH	970,874	970,874				970,874			4.6
Indiana	465,638					465,638	26,895	NH	438,743	438,743				438,743			7.8
Iowa	423,886	7,366	F, P	3	12,717	403,803	28,805	NH	374,998	374,998				374,998			9.0
Kansas	*378,781	87,330	F, NH, IC	2	7,575	283,876			283,876	283,876				283,876			[illegible]
Kentucky	184,369					184,369			184,369	184,369							10.9
Louisiana	183,977			3	5,519	178,458	1	F	178,457	178,434	23	4	(10)				9.4
Maine	116,994	1,200	F			115,794			115,794	110,924	4,870	1	NH	110,924	4,870	NH	8.7
Maryland	207,652	1,373	F			206,279	10,616	[12] NH	195,663	193,961	1,702	3	U	[15] 195,663			8.6
Massachusetts	*590,625	2,797	F, E			587,828	21,093	F, NH	566,735	566,735				566,735			3.8
Michigan	735,593					735,593	35,763	NH	699,830	698,681	1,149	1½	AV	698,681	1,149	AV	7.7
Minnesota	419,454	1,908	(13)	3	12,534	405,012	43,500	NH	361,512	361,512				361,512			8.3
Mississippi	130,156	2,180	F	2	2,547	125,429			125,429	112,666	12,763	1	NH	112,666	12,763	NH	16.5
Missouri	505,677			3	15,170	490,507	11,743	NH	478,764	478,764				478,764			5.4
Montana	*90,567	2,562	F, E	2	2,523	85,482	12,211	NH	73,271	73,271				73,271			33.2
Nebraska	*224,195	798	F	3	6,726	216,671	2,414	E, D	214,275	214,257							11.2
Nevada	*27,204	2,497	F, E, IC			24,707	2,352	NH	22,355	22,355				22,355			28.5
New Hampshire	70,652					70,652	2,011	NH	68,641	68,641				68,641			16.8
New Jersey	*732,761	164,922	[14] F, P, NH, E			567,839			567,839	567,727	112	2	B	567,727	112	B	3.9
New Mexico	*60,997	3,922	F, E, IC	2	898	56,177	5,043	NH	51,134	51,134				51,134			12.9
New York	1,569,141	52,511	F, P	1	15,167	1,501,463	37,221	NH	1,464,242	1,464,242				1,464,242			1.3
North Carolina	284,214	2,540	F, AV	1	1,877	279,797			279,797	273,686	6,111	1	NH	273,686	6,111	NH	11.2
North Dakota	96,875					96,875	21,485	NH	75,390	75,390				75,390			17.6
Ohio [5]	*1,303,642	239,900	F, E, IC	3	31,912	1,031,830	673	D, R	1,031,157	910,214	120,943	1	NH	910,214	120,943	NH	8.6
Oklahoma	*312,165	33,748	F, IC, NH	3	7,985	270,432			270,432	270,432				270,432			7.5
Oregon	*165,978					165,978	20,464	NH, E	145,514	144,917	597	1	AV	144,917	597	AV	6.7
Pennsylvania [16]	1,136,343			2	22,714	1,113,629			1,113,629	1,113,629							8.7
Rhode Island	*233,167	124,303	F, E			108,864	6,030	NH, E	102,834	102,834				102,834			9.3
South Carolina	130,606					130,606	1,960	F	128,646	128,646							15.6
South Dakota	103,122			4	4,125	98,997			98,997	89,245	9,752	2	NH	89,245	9,752	NH	13.9
Tennessee	207,857	4,118	F, P	1	2,075	201,634	7	D, R	201,627	201,627							8.7
Texas	893,802	9,824	F	1	8,840	875,138	84,133	NH	791,005	791,005				791,005			11.1
Utah	64,836			3	1,978	62,858			62,858	62,858							14.9
Vermont	48,550					48,550			48,550	48,550							10.0
Virginia	264,102					264,102	14,562	NH	249,540	249,540				249,540			12.6
Washington	260,778					260,778	21,591	NH	239,187	239,187				239,187			10.1
West Virginia	147,610					147,610	5,217	NH	142,393	142,393				142,393			15.8
Wisconsin	431,513			2½	10,788	420,725	35,744	NH	384,981	384,981				384,981			1.5
Wyoming	44,111					44,111			44,111	44,111							25.5
District of Columbia	147,607	42,186	F, P	2	1,601	103,820	691	NH	103,129	103,129				103,129			−0.9
Total	17,220,567	882,618			201,812	16,136,137	681,656		15,454,481	15,210,135	244,346			12,485,421	162,446		7.5

The following symbols are used to designate certain classes or uses of motor fuel exempted from tax payment, subject to refund of the tax, or taxed at a lower rate:

F—Sales to Federal Government.
P—(Public) sales to State, county, or municipal governments.
E—Fuel exported to other States or countries.
IC—Fuel moving through the State in interstate commerce.
NH—Uses other than for propelling motor vehicles on the highways.
C—Use in public construction.
AV—Aviation use.
U—Use in vehicles licensed to operate exclusively in cities.
B—Motor-boat use.
D—Fuel destroyed by fire, acts of God, etc.
R—Routine refunds (overpayment, etc.).

[1] In this column is given the total amount of motor fuel reported, prior to deduction of exempted fuel, allowance for shrinkage, etc., and amount subject to refund. Wherever possible, fuel exempted because of export or interstate movement, or to avoid duplication of tax payment, has been eliminated, in order that the total may represent as closely as possible the total consumption of motor fuel in the State. Starred items indicate that unknown amounts of export sales or fuel moving in interstate commerce are included in the total shown

[2] A number of States failed to report exempted fuel. Symbols are given only where amounts are reported.

[3] Allowances for loss by leakage, evaporation, etc., and percentage discounts allowed to distributors. Percentages are given only where amounts are reported. In some States the percentage is computed on the gross reported; in others on the net after deduction of exempted fuel. In some States the percentage is fixed, in others it is the maximum allowable

[4] In the case of Arkansas and Colorado, where the rate was changed during the year, the amounts taxed at the lower rates, 6 and 4 cents, respectively, are shown under this heading.

[5] The purpose of this classification is to distinguish between the consumption of taxed motor fuel by motor vehicles operating on the highways, and consumption for other purposes. In the case of States which do not make this distinction, the classification is omitted.

[6] These percentages are based on the amount taxed for highway use, except in the case of those States in which there is no classification by use. In those cases the percentage is based on the total amount on which tax was earned. The total on which the Nation-wide percentage is based is 15,292,035,000 gallons. A decrease (District of Columbia only) is indicated by a minus sign.

[7] Refunds on nonhighway use not allowed after Feb. 12, 1934.

[8] 7,412,000 gallons at 6 cents prior to Feb. 13, 1934. Taxed at reduced rates at State borders: At 5 cents, 138,000 gallons; at 4 cents, 8,677,000 gallons; at 2 cents, 935,000 gallons.

[9] Estimated by State

[10] Actual allowance reported; no fixed percentage.

[11] Rate of 4 cents per gallon applies to any gas-generating liquid having a flash point below 110° F. Additional 1-cent rate applies only to liquid fuels commonly used to propel motor vehicles or motors.

[12] Refunds are made on all nonhighway uses with the exception of fuel used in commercial motor boats.

[13] Railroad usage.

[14] Also fuel used in busses which pay a municipal or franchise tax.

[15] A 3-cent tax is imposed on motor-vehicle fuel, and a 1-cent tax on all liquid fuels, including fuel oil and kerosene. The gross amount of liquid fuel reported was 1,303,642,000 gallons; the gross amount of motor-vehicle fuel reported was 1,254,786,000 gallons.

[16] Tax is imposed on all liquid fuels, including fuel oil and kerosene, usable in internal combustion engines.

STATE MOTOR-FUEL TAX EARNINGS, 1934

[Compiled for calendar year from reports of State authorities [1]]

State	Tax rate per gallon		Date of rate change	Gross tax assessed	Refunds earned or paid [5]	Net tax on all motor-fuel taxed [4]	Classification of tax earnings					Other earnings in connection with motor-fuel tax [3]					Grand total earnings
							By rate of tax			By use of fuel [2]							
	On Jan. 1	On Dec. 31					At full rate	At reduced rates [6]		For highway use [2]	For other uses	Distributors' licenses	Dealers' licenses	Inspection fees	Other fees, etc.	Total	
								Rate per gallon	Amount								
	Cents	*Cents*		*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*Cents*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Alabama	6	6		9,299		9,299	9,299										9,299
Arizona	5	5		3,542	514	3,028	3,028			3,028					1	1	3,029
Arkansas	6	6½	Feb. 3	8,118	254	7,864	7,047	6, 5, 4, 2	[7] 817	[8] 7,481	[8] 383						7,864
California	3	3		39,621	3,661	35,960	35,960			35,960		10				10	35,970
Colorado	[9] 4	4	Feb. 1 and Sept. 1.	7,591	1,116	6,475	3,719	[6] 4	2,756	6,475							6,475
Connecticut	2	2		5,099	126	4,973	4,973			4,973			([10])				4,973
Delaware	3	3		1,246	61	1,185	1,185			1,185							1,185
Florida	7	7		16,499		16,499	16,499						[11] 35			35	16,534
Georgia	6	6		14,366		14,366	14,366										14,366
Idaho	5	5		3,169	298	2,871	2,865	2½	6	2,865	6				1	1	2,872
Illinois	3	3		30,772	1,646	29,126	29,126			29,126					5	5	29,131
Indiana	4	4		18,626	1,076	17,550	17,550			17,550					20	20	17,570
Iowa	3	3		12,114	864	11,250	11,250			11,250		1			4	5	11,255
Kansas	3	3		8,516		8,516	8,516			8,516		5		76	37	118	8,634
Kentucky	5	5		9,218		9,218	9,218								3	3	9,221
Louisiana	5	5		8,923		8,923	8,922	4	1								8,923
Maine	4	4		4,602	116	4,486	4,437	1	49	4,437	49						4,486
Maryland	4	4		8,251	442	7,809	7,758	3	51	[12] 7,809							7,809
Massachusetts	3	3		17,635	633	17,002	17,002			17,002							17,002
Michigan	3	3		22,068	1,090	20,978	20,961	1½	17	20,961	17		4		2	6	20,984
Minnesota	3	3		12,150	1,305	10,845	10,845			10,845			1	97		98	10,943
Mississippi	6	6		7,519	631	6,888	6,760	1	128	6,760	128				[13] 137	137	7,025
Missouri	2	2		9,810	235	9,575	9,575			9,575				98	8	106	9,681
Montana	5	5		4,274	610	3,664	3,664			3,664							3,664
Nebraska	4	4		8,667	97	8,570	8,570							85	1	86	8,656
Nevada	4	4		988	94	894	894			894							894
New Hampshire	4	4		2,826	80	2,746	2,746			2,746							2,746
New Jersey	3	3		17,035	1	17,034	17,032	2	2	17,032	2		25	39		64	17,098
New Mexico	5	5		2,809	252	2,557	2,557			2,557		9	9			18	2,575
New York	3	3		45,041	1,117	43,927	43,927			43,927			58			58	43,985
North Carolina	6	6		16,788	306	16,482	16,421	1	61	16,421	61			[14] 704	5	709	17,191
North Dakota	3	3		2,906	644	2,262	2,262			2,262							2,262
Ohio	4	4		38,982	1,364	37,618	36,409	1	1,209	36,409	1,209						37,618
Oklahoma	4	4		10,817		10,817	10,817			10,817					4	4	10,821
Oregon	5	5		8,299	1,047	7,252	7,246	1	6	7,246	6						7,252
Pennsylvania	3	3		33,409		33,409	33,409								4	4	33,413
Rhode Island	2	2		2,177	120	2,057	2,057			2,057			3			3	2,060
South Carolina	6	6		7,836	117	7,719	7,719										7,719
South Dakota	4	4		3,960	195	3,765	3,570	2	195	3,570	195						3,765
Tennessee	7	7		14,114		14,114	14,114										14,114
Texas	4	4		35,005	3,365	31,640	31,640			31,640					111	111	31,751
Utah	4	4		2,514		2,514	2,514						1			1	2,51
Vermont	4	4		1,942		1,942	1,942										1,94
Virginia	5	5		13,205	728	12,477	12,477			12,477							12,47
Washington	5	5		13,039	1,080	11,959	11,959			11,959							11,95
West Virginia	4	4		5,905	209	5,696	5,696			5,696		2	5		1	8	5,70
Wisconsin	4	4		16,829	1,430	15,399	15,399			15,399							15,39
Wyoming	4	4		1,764		1,764	1,764					[15] 3			1	4	1,76
Dist. of Columbia	2	2		2,077	14	2,063	2,063			2,063							2,06
Detailed totals [16]										434,634	2,056						
Grand totals	[17] 3.66			591,995	26,968	565,027	559,729		5,298			30	141	1,099	345	1,615	566,64

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[1] See preceding table for gross gallons of motor fuel reported, exemptions, allowances, etc., gross gallons taxed, gallons subject to refund, net gallons taxed, and information regarding classes of use exempted, subject to refund, or taxed at lower rates.

[2] The purpose of this classification is to distinguish between the tax earnings on motor fuel sold for use in motor vehicles on the highways and tax earnings on motor fuel sold for other uses. In the case of those States that do not make this distinction, the classification is omitted.

[3] Amounts less than $500 not tabulated.

[4] In the great majority of cases the assessments or earnings of the calendar year were reported. A few States reported the actual collections of the year, which lag the assessments by 1 to 2 months.

[5] In most cases the refunds reported were those actually paid during the year, rather than refunds claimed on motor fuel purchased during the year. The error involved in deducting refunds paid from gross tax assessed tends to balance over an annual period. The refunds tabulated include both refunds of the entire tax and partial refunds.

[6] In the case of Arkansas and Colorado, where the rate was changed during the year, the tax earnings at the lower rates, 6 and 4 cents, respectively, are shown under this heading.

[7] Includes $445,000 on 6-cent tax prior to Feb. 13, 1934, and amounts at reduced rates at State borders, as follows: At 5 cents, $7,000; at 4 cents, $347,000; at 2 cents, $18,000.

[8] Estimated by State.

[9] Rate was 5 cents from Feb. 1 to Aug. 31, 1934.

[10] Retail gasoline station licenses, $45,000, included in report on motor-vehicle receipts.

[11] Includes distributors' licenses.

[12] Refunds are made on all nonhighway uses with the exception of fuel used in commercial motor boats. Earnings on motor-boat fuel (amount not reported) are included.

[13] Includes $138,500, earnings on special gasoline tax collected in Gulf Coast counties (Hancock, Harrison, and Jackson) for seawall protection, and $1,559 in penalties, less $2,629, refunds for notary fees.

[14] Inspection fees on gasoline and kerosene; bulk of receipts on gasoline.

[15] Includes dealers' licenses.

[16] Classification by use includes 36 States and the District of Columbia.

[17] Weighted average rate.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Fund	Mileage	Estimated Total Cost	1934 Public Works Fund	1935 Public Works Funds	Mileage	1934 Public Works Fund	1935 Public Works Funds	Mileage	1934 Public Works Fund	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ [illegible]	$ 3,460,745	$ 139,902	358.2	$ 2,147,304	$ 460,140	$ 1,364,071	109.8	$ 20,073	$ 195,768	11.8	$ [illegible]	$ [illegible]
Arizona	3,855,555	1,738,712	[illegible]	3,629,744	563,373	362.8	902,109		775,339	32.2	15,039			[illegible]	
Arkansas	3,334,167	1,714,000	3,828,359	2,576,551	629,904	184.5	1,662,770	700,927	742,291	76.2	39,563	229,602	6.2	17,126	[illegible]
California	7,912,928	3,713,643	11,199,998	7,789,341	609,765	370.4	3,163,930	122,227	2,122,000	55.5		[illegible]	[illegible]	1,760	[illegible]
Colorado	[illegible]	2,424,504	[illegible]	[illegible]	1,845,044	262.3	[illegible]	77,176	[illegible]	30.5				[illegible]	[illegible]
Connecticut	1,404,213	[illegible]	1,135,531	[illegible]		20.8	[illegible]	[illegible]	554,726	17.1					[illegible]
Delaware	377,566	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8,477	[illegible]	3.2	[illegible]			40	[illegible]
Florida	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	711,020	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Georgia	[illegible]	[illegible]	[illegible]	3,977,140	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Idaho	[illegible]	1,131,916	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39.7		[illegible]	.1	7,986	[illegible]
Illinois	[illegible]	2,408,778	[illegible]	[illegible]	149,249	[illegible]	[illegible]	[illegible]	[illegible]	67.4	[illegible]	[illegible]	.1	[illegible]	
Indiana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Iowa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]
Kansas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	.9	[illegible]	
Kentucky	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Louisiana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
Maine	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]
Maryland	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]
Massachusetts	1,161,716	[illegible]	[illegible]	[illegible]		7.4	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]
Michigan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Minnesota	[illegible]	2,553,733	6,200,552	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	110.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mississippi	[illegible]	2,832,182	6,647,003	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	144.1	[illegible]	[illegible]	30.3	[illegible]	[illegible]
Missouri	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	217.8	[illegible]	[illegible]	[illegible]	78.2	249,960	[illegible]	[illegible]	80,043	
Montana	[illegible]	[illegible]	[illegible]	4,345,161	1,764,369	577.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	17.3	[illegible]	[illegible]
Nebraska	[illegible]	[illegible]	[illegible]	[illegible]	216,519	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Nevada	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	147.2	17,734	[illegible]	[illegible]	[illegible]	[illegible]
New Hampshire	[illegible]	[illegible]	957,865	[illegible]	[illegible]	15.8	[illegible]		[illegible]	7.5					[illegible]
New Jersey	3,173,019	[illegible]	[illegible]	[illegible]	29,746	38.1	1,770,707	1,113,074	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
New Mexico	[illegible]	1,676,769	[illegible]	[illegible]	1,047,173	374.7	[illegible]		[illegible]	[illegible]	[illegible]				
New York	[illegible]	[illegible]	11,942,977	[illegible]	[illegible]	[illegible]	7,014,830	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
North Carolina	4,761,147	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.1	[illegible]	[illegible]
North Dakota	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ohio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
Oklahoma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70.7	[illegible]	[illegible]	7.9	[illegible]	[illegible]
Oregon	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]
Pennsylvania	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Rhode Island	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					[illegible]
South Carolina	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
South Dakota	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Tennessee	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Texas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Utah	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1.1	[illegible]	[illegible]
Vermont	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	14.1	[illegible]	[illegible]		[illegible]	[illegible]
Virginia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1	[illegible]	[illegible]
Washington	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	.7		[illegible]
West Virginia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
Wisconsin	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1	[illegible]	[illegible]
Wyoming	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	141,0[illegible]1	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
District of Columbia															
Hawaii	[illegible]	[illegible]	[illegible]	[illegible]		19.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4	[illegible]	[illegible]
TOTALS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,354,328	$ 1,064,961	$ 2,000,380	$ 1,872,024	$ 114,375	49.1	$ [illegible]	$ 453,060	$ [illegible]	[illegible]	$ 23,873	$ [illegible]	3.1	$ [illegible]	$ [illegible]
Arizona	758,482	[illegible]	735,883	622,304	86,475	15.1	[illegible]	[illegible]	[illegible]	.5				[illegible]	[illegible]
Arkansas	[illegible]	[illegible]	1,302,627	[illegible]	[illegible]	48.3	510,198	[illegible]	[illegible]	[illegible]	101,076	[illegible]	[illegible]	[illegible]	[illegible]
California	[illegible]	[illegible]	[illegible]	3,649,724	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.0		[illegible]	[illegible]	[illegible]	[illegible]
Colorado	[illegible]	190,000	[illegible]	[illegible]	164,411	40.4	11,229	[illegible]		.8				[illegible]	[illegible]
Connecticut	[illegible]	[illegible]	[illegible]	802,407	9,362	10.2	[illegible]		142,521	1.5		[illegible]	1.3		[illegible]
Delaware	[illegible]	210,849	542,664	[illegible]	73,675	8.1	18,165		18,165	1.1				[illegible]	[illegible]
Florida	[illegible]	[illegible]	[illegible]	1,439,771	[illegible]	21.4	156,128	2,324	[illegible]	1.4		[illegible]	[illegible]	[illegible]	[illegible]
Georgia	[illegible]	[illegible]	2,414,317	[illegible]	[illegible]	74.8	793,177	[illegible]	404,136	18.2		[illegible]	1.2	[illegible]	[illegible]
Idaho	[illegible]	301,126	1,222,156	[illegible]	27,081	20.9	190,673		[illegible]	[illegible]		[illegible]	[illegible]	46,349	[illegible]
Illinois	[illegible]	2,230,350	6,593,163	[illegible]	8,850	66.5	2,121,438	1,036,345	[illegible]	11.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Indiana	[illegible]	[illegible]	3,615,513	3,362,976	134,436	70.4	[illegible]	[illegible]	[illegible]	29.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Iowa	[illegible]	1,311,000	2,303,093	[illegible]	[illegible]	58.9	1,408,378	[illegible]	[illegible]	[illegible]		[illegible]	.1	39	[illegible]
Kansas	[illegible]	1,430,949	[illegible]	[illegible]	[illegible]	45.8	1,059,769		1,044,406	11.3	48,919	10,980	1.2		
Kentucky	1,927,828	[illegible]	1,607,817	1,476,834	71,226	35.8	945,972	389,559	528,141	9.9	30,000	[illegible]	3.5	31,436	213,305
Louisiana	1,708,577	744,560	948,832	793,980	147,468	23.5	1,197,913	896,730	259,141	14.9	10,666	203,661	2.7	7,200	134,271
Maine	960,426	484,379	925,109	872,233	47,377	17.5	360,761	83,155	271,642	3.3		158,253	2.7	5,038	6,907
Maryland	891,132	452,515	390,021	384,017		3.6	1,075,978	262,457		.9				244,658	452,515
Massachusetts	5,007,199	847,600	2,249,980	2,102,182	98,359	14.9	3,071,272	2,876,372	159,924	5.0				28,646	579,317
Michigan	3,500,637	1,613,142	3,392,363	3,118,735	133,100	40.2	1,642,750	342,450	1,262,400	17.2	19,400	130,975	2.3	[illegible]	86,657
Minnesota	3,719,143	1,421,494	3,575,293	3,136,040	376,049	113.9	1,183,363	513,160	575,719	17.1	4,220	54,188	3.0	65,722	[illegible]
Mississippi	1,744,669	354,022	1,166,485	1,033,466	114,956	37.0	817,550	626,097	120,417	23.0	30,343	18,487	2.5	48,163	100,163
Missouri	4,014,501	919,152	3,101,773	3,001,268	24,854	52.9	1,142,578	867,762	228,978	12.4		665,320	3.1	150,471	
Montana	1,115,962	113,092	1,093,057	1,016,328	49,258	36.6	94,702	64,410	15,752	6.0	2,474	7,553	1.0	32,743	40,949
Nebraska	1,957,240	991,091	2,498,414	1,915,583	548,278	45.3	296,070		296,070	4.5				41,657	146,743
Nevada	600,051	100,000	559,562	473,901	57,842	10.8					26,150	41,402	.6		756
New Hampshire	740,335	242,465	845,980	668,776	173,847	18.7	53,951		53,741	.5	13,044		.4	58,515	14,677
New Jersey	3,117,921	1,809,500	3,080,011	2,810,715	108,606	22.9	1,225,905	182,690	804,667	5.9		631,441	.9	[illegible]	264,787
New Mexico	1,574,158	529,506	1,778,171	1,535,354	180,097	40.2	69,432		69,432	1.7	1,010	187,963	1.1	77,794	36,014
New York	[illegible]	3,961,690	8,085,610	7,217,830	384,600	63.4	3,394,541	875,017	2,964,090	22.9		219,150	.2	162,814	333,850
North Carolina	2,780,573	1,210,236	2,791,849	2,135,990	634,661	96.8	548,276	103,576	426,700	13.4	91,217	91,264	2.1	49,790	57,611
North Dakota	1,451,112	734,741	1,341,415	1,241,533	92,515	54.5	188,029	99,844	88,185	9.9	87,346	190,563	16.4	22,388	363,480
Ohio	4,335,686	2,359,504	5,155,741	4,238,314	434,145	69.0	1,611,417	93,352	1,374,172	13.5		80,000	.3	4,020	471,186
Oklahoma	2,304,200	1,171,295	2,415,796	2,112,039	220,827	49.2	786,181	192,161	575,152	9.0		126,468	1.9		248,847
Oregon	1,526,724	867,977	1,617,923	1,415,650	150,853	32.8	619,349	66,635	544,705	9.3	518	80,000	.2	43,921	32,418
Pennsylvania	4,854,988	2,397,703	5,208,661	4,279,869	725,785	72.7	1,354,210	511,144	749,944	11.8		288,881	.9	63,976	133,092
Rhode Island	579,625	235,760	555,890	518,991	36,001	8.0	105,759		105,759	.9				60,634	144,000
South Carolina	1,764,791	488,000	1,226,620	1,199,312	23,620	38.2	420,872	156,274	251,547	12.8	8,705	15,412	.1		197,422
South Dakota	1,502,870	761,911	1,232,982	1,188,674	43,905	41.5	241,429	77,024	164,405	9.2	40,456	125,639	7.4	136,716	427,962
Tennessee	2,123,155	1,121,789	2,209,866	1,921,523	264,518	26.3	696,283	201,632	494,651	7.6		115,946	.7		246,675
Texas	6,642,863	1,795,000	6,049,343	5,708,102	216,679	134.6	1,662,930	671,837	814,902	21.3	16,465	398,296	8.7	246,459	365,123
Utah	773,826	533,173	812,144	649,146	97,066	20.8	650,283	129,130	433,800	13.5				550	2,306
Vermont	500,509	240,611	636,840	458,671	96,235	15.5	137,402	26,801	105,082	2.7		39,244	.9	15,036	
Virginia	1,948,780	956,021	2,266,435	1,681,361	352,905	34.1	702,604	246,442	396,439	10.3	13,975	155,506	4.2	7,002	51,170
Washington	1,977,260	776,603	2,330,254	1,922,046	385,313	42.5	412,559	53,369	359,190	5.0		7,370		1,845	24,730
West Virginia	1,342,270	570,085	1,108,178	1,042,973	28,109	18.6	494,743	270,594	224,149	6.8	28,642	47,791	.6	61	270,035
Wisconsin	2,596,143	1,379,513	3,102,009	2,509,104	514,579	62.2	629,047		629,047	8.9	57,664	215,499	4.2	29,375	20,389
Wyoming	1,125,332	29,416	977,168	971,191	2,784	22.5	162,381	147,667	14,132	3.4				6,474	12,500
District of Columbia	946,445	131,051	877,332	696,281	131,051	6.5	250,164	250,164		.2					
Hawaii															
TOTALS	115,617,401	48,020,938	111,510,588	97,431,410	9,404,416	2,021.2	41,300,530	15,058,226	22,570,806	453.2	864,143	6,505,549	104.7	2,263,622	9,540,167

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,360	$ 2,016,508	$ 1,803,113	$ 196,710	143.0	$ 822,670	$ 157,735	$ 634,[illegible]	52.6		$ 106,340	10.6	$ 41,540	$ 104,426
Arizona	599,427	394,030	985,[illegible]	530,962	357,054	66.5	644,037	45,000	[illegible]	45.6				23,461	77,009
Arkansas	1,449,634	657,024	1,337,268	1,249,465	125,693	176.3	650,656	147,095	501,385	65.9		224,446	27.1	53,114	
California	3,480,440	1,999,203	4,060,207	3,154,843	216,000	180.1	1,833,841	327,597	1,364,725	56.4		202,527	9.4	1,700	155,951
Colorado	1,715,632	871,502	2,601,724	1,600,632	551,362	272.6	550,309	110,000	320,140	39.2					
Connecticut	659,120	420,868	[illegible]7,300	659,120	10,839	14.9	222,830		292,350	4.5					185,033
Delaware	481,113	290,349	460,022	269,669	196,544	57.1	269,716	219,448	41,690	14.2					2,615
Florida	1,[illegible],316	1,043,543	1,[illegible],676	1,274,756	331,430	88.5	794,065		646,064	41.3		33,738	4.7	23,060	[illegible]
Georgia	2,320,377	1,278,373	1,662,[illegible]	1,530,474	[illegible]	10[illegible]	1,[illegible]	[illegible]	[illegible]	74.[illegible]				139,711	[illegible]
Idaho	1,101,[illegible]	824,460	1,[illegible]	1,004,[illegible]	795,344	196.[illegible]	247,[illegible]		247,[illegible]	[illegible]				27,032	174,944
Illinois	[illegible]	4,[illegible]	[illegible]	[illegible]	91,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible],156	7.8	14,068	314,400
Indiana	731,772	151,472	[illegible]	[illegible]	6,600	44.7	[illegible]	[illegible]	[illegible]	[illegible]				35,227	40,347
Iowa	[illegible]	1,[illegible],000	2,[illegible],545	[illegible]	[illegible]	[illegible]	1,[illegible]	[illegible]	1,141,[illegible]	[illegible]	$ [illegible]	16,[illegible]	[illegible]	727	
Kansas	[illegible],421	1,[illegible]	[illegible]	1,1[illegible]	[illegible]	[illegible]	1,[illegible]	[illegible]	1,1[illegible]	77.[illegible]			1.[illegible]		
Kentucky	1,[illegible]	1,[illegible]	2,1[illegible]	1,7[illegible],044	[illegible]	[illegible]41.[illegible]	1,[illegible]	[illegible]	1,[illegible]	[illegible]		[illegible]	[illegible]	13,[illegible]	40,[illegible]
Louisiana	1,4[illegible]	[illegible]	1,1[illegible]	1,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.[illegible]	114	[illegible]
Maine	[illegible]	[illegible]	1,2[illegible],714	[illegible],404	[illegible]	[illegible].1	[illegible]		[illegible]	1.4				[illegible]	[illegible]
Maryland	[illegible]	1,[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Massachusetts	[illegible]	[illegible]	477,43[illegible]	[illegible],741		[illegible]			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Michigan	[illegible]	1,[illegible]	[illegible]	[illegible],440	[illegible]	[illegible]	1,[illegible]	[illegible]	1,447,417	[illegible]		[illegible]	[illegible]	[illegible]	
Minnesota	[illegible]	1,4[illegible]	[illegible]	2,17[illegible]	640,515	715.0	[illegible]	[illegible]	[illegible]	64.1		11[illegible]	3.2	[illegible]	[illegible]
Mississippi	[illegible]	[illegible]	1,[illegible]	1,04[illegible],747	15,[illegible]	145.1	[illegible],477	[illegible]	[illegible]	40.3		1[illegible]	16.5	[illegible]	[illegible],152
Missouri	[illegible]	[illegible]	3,14[illegible]	[illegible]	4[illegible]1,734	[illegible]	1,[illegible]	[illegible]1	1,7[illegible]	[illegible].5		[illegible]4,335	24.0	1,716	
Montana	1,[illegible]27	442,494	[illegible]	1,74[illegible]	[illegible]	[illegible]	311,[illegible]		11,474	31.9	[illegible]	[illegible]	11.7	[illegible]	
Nebraska	1,[illegible]7,140	[illegible],091	[illegible]	1,457,240	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		77,414	1[illegible]		[illegible]
Nevada	1,1[illegible]	[illegible]	1,[illegible]	1,11[illegible]	447,0[illegible]	[illegible]	1[illegible]	1[illegible],000	1[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	64,1[illegible]
New Hampshire	[illegible]	[illegible]	[illegible]	[illegible]	74,757	[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]					1[illegible]
New Jersey	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	1.7		17[illegible]	1.1		15[illegible]
New Mexico	1,[illegible],164	[illegible]	1,[illegible]	1,[illegible],146	771,[illegible]	[illegible]	[illegible],721	[illegible],371	[illegible]	41.4					1[illegible]
New York	3,[illegible],763	[illegible]	4,111,171	3,0[illegible]	[illegible],149	113.[illegible]	4,1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		7.4		[illegible]
North Carolina	2,[illegible],[illegible]73	1,700,[illegible]	[illegible]	2,17[illegible]	[illegible]7,947	319.4	1,0[illegible]	1[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
North Dakota	1,4[illegible]1,11[illegible]	73[illegible]	1,[illegible]	1,17[illegible],848	[illegible],074	[illegible]7.7	[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ohio	3,271,148	1,9[illegible]	4,1[illegible]	[illegible]	1[illegible]	[illegible]	1,41[illegible]	[illegible]	1,[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Oklahoma	[illegible]	1,171,[illegible]	[illegible]	[illegible]	[illegible],149	272.4	1,2[illegible]	[illegible]	[illegible]	[illegible].1		[illegible]	[illegible]		[illegible]
Oregon	1,[illegible]	777,[illegible]	2,11[illegible]	1,[illegible]	447,577	[illegible].3	[illegible]	[illegible]	[illegible]	1[illegible].0				1[illegible]17	[illegible]
Pennsylvania	7,744,[illegible]	[illegible]	[illegible]	[illegible]	341,038	[illegible].1	3,7[illegible],144	1,[illegible]	2,1[illegible]	[illegible]		17[illegible]	[illegible].0	[illegible]	
Rhode Island	[illegible],716	[illegible],040	443,74[illegible]	[illegible],716		[illegible].1	21[illegible]		21[illegible]	[illegible].7		[illegible]	1.[illegible]		[illegible]
South Carolina	1,[illegible],741	1,34[illegible]	1,[illegible]	1,[illegible]	107,07[illegible]	[illegible].1	1,460,[illegible]	[illegible]	1,14[illegible]	167.5				14,[illegible]	[illegible]
South Dakota	1,[illegible],870	751,311	1,4[illegible],743	1,7[illegible],467	131,044	[illegible].9	[illegible]	174,741	[illegible],214	[illegible]		14[illegible]	[illegible].1	[illegible]	[illegible]
Tennessee	2,1[illegible]	1,[illegible]	[illegible]	1,771,[illegible]	[illegible],306	145.3	[illegible]7,013	[illegible],714	[illegible]	[illegible]	17,694	[illegible]	[illegible].1	[illegible]	[illegible],424
Texas	[illegible]	[illegible],000	7,114,[illegible]	[illegible],740	[illegible]	[illegible].7	2,311,[illegible]	34,517	2,[illegible],130	170.8		[illegible]	10.[illegible]	[illegible]	[illegible]
Utah	1,048,[illegible]	[illegible],173	1,[illegible],776	[illegible]	277,173	217.4	407,[illegible]1	[illegible]	[illegible],000	[illegible]					1,[illegible]
Vermont	[illegible]	241,384	[illegible]	[illegible]	[illegible]	47.9	[illegible]		74,410	[illegible]				[illegible]	[illegible]
Virginia	1,7[illegible],770	[illegible]	1,71[illegible]	1,[illegible]	[illegible]	[illegible]	[illegible]	11[illegible]	[illegible]1,717	[illegible]	[illegible]	19[illegible]	1[illegible]	1[illegible],141	[illegible]
Washington	1,0[illegible]73	776,0[illegible]	1,[illegible]	1,[illegible]73	[illegible]	[illegible].1	[illegible]		[illegible]	[illegible]					1,[illegible]
West Virginia	1,113,[illegible]9	[illegible]	839,9[illegible]7	796,133		47.[illegible]	[illegible]	31[illegible],068	[illegible]	[illegible]		47,[illegible]	[illegible]	[illegible]	17[illegible],763
Wisconsin	[illegible],200	1,743,[illegible]	[illegible]	[illegible]	[illegible]	174.7	1,551,[illegible]1	[illegible],450	1,1[illegible]17	[illegible]		127,338	[illegible]	21,47[illegible]	11[illegible]
Wyoming	1,1[illegible]	[illegible]	1,[illegible]	1,047,[illegible]	[illegible]	[illegible]	442,373	[illegible]	[illegible],548	11[illegible]		[illegible],307	[illegible]	[illegible]	1,[illegible]
District of Columbia	[illegible]	730,791	1,1[illegible]	971,729	184,[illegible]	10.4	390,065		[illegible]	2.[illegible]		7[illegible]	.[illegible]	[illegible]	1[illegible],037
Hawaii	177,71[illegible]	361,000	17[illegible]	177,716		4.3						161,653	4.[illegible]		1[illegible],347
TOTALS	[illegible]	58,043,4[illegible]	[illegible]	[illegible],877,442	11,[illegible],437	10,021.3	[illegible],[illegible]93,435	9,8[illegible],427	[illegible],[illegible]4,167	[illegible]	513,095	4,440,[illegible]4	393.0	[illegible]	[illegible],034,424

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF JULY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 N.I.R. Act June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
	$	$	$	$	$		$	$	$		$	$		$	$
Alabama	8,373,135	4,254,342	10,544,744	[illegible]	455,330	550.3	3,756,109	1,110,985	2,362,031	186.9	49,951	447,178	26.4	73,309	1,034,647
Arizona	5,211,960	2,641,975	6,801,137	4,933,509	1,006,382	466.5	1,874,076	174,322	1,496,161	78.5	15,039			[illegible]	[illegible]
Arkansas	6,748,335	3,428,049	7,113,444	6,417,647	[illegible]	409.1	2,325,623	1,098,989	1,503,655	153.6	140,539	770,583	33.1	[illegible]	[illegible]
California	[illegible]	7,938,006	20,602,040	14,793,908	1,672,798	616.3	7,577,909	802,964	4,557,069	120.0		1,363,621	77.7	[illegible]	318,709
Colorado	[illegible]	[illegible]	10,014,639	6,677,716	2,215,317	675.4	1,167,154	136,405	836,331	70.5				38,409	[illegible]
Connecticut	[illegible]	1,454,368	2,571,380	2,570,712	22,251	46.0	1,553,394	235,028	920,127	23.2		134,513	1.7		177,377
Delaware	1,819,068	923,395	2,207,097	1,694,418	576,536	110.8	433,426	223,925	200,847	18.5	578			167	145,013
Florida	[illegible]	2,661,343	6,923,253	5,074,637	706,346	234.5	1,561,213	69,148	1,406,517	74.7	23,968	378,683	7.8	64,121	150,298
Georgia	10,041,145	5,113,431	9,067,538	7,600,434	971,644	539.0	3,628,365	1,313,406	1,703,148	173.3	6,394	217,429	5.0	464,391	1,250
Idaho	[illegible]	[illegible]	[illegible]	4,273,123	788,715	407.4	1,119,277	131,759	954,290	67.2		30,670	[illegible]	[illegible]	[illegible]
Illinois	[illegible]	8,921,401	[illegible]	12,177,189	249,902	311.8	11,563,529	5,304,438	6,554,131	364.9	50,260	[illegible]	[illegible]	[illegible]	[illegible]
Indiana	10,037,343	[illegible]	[illegible]	[illegible]	157,034	243.3	[illegible]	[illegible]	[illegible]	203.8	[illegible]	[illegible]	16.4	[illegible]	[illegible]
Iowa	[illegible]	[illegible]	[illegible]	9,372,197	[illegible]	[illegible]	4,906,043	176,717	[illegible]	377.2		[illegible]	[illegible]	744	[illegible]
Kansas	10,083,604	5,117,675	11,266,362	[illegible]	1,323,424	918.4	4,177,107	736,982	[illegible]	214.1	32,417	[illegible]	[illegible]	8,374	
Kentucky	7,617,359	3,816,311	7,539,739	6,657,329	543,551	560.4	3,685,737	723,296	[illegible]	241.6	30,000	130,221	7.3	106,735	366,639
Louisiana	[illegible]	3,963,932	5,011,374	4,279,444	342,291	152.3	3,432,133	1,340,921	1,395,906	80.9	130,479	333,452	13.4	15,747	392,282
Maine	3,369,917	[illegible]	4,162,421	3,296,241	756,964	173.3	832,830	94,506	784,708	18.2		158,253	2.8	19,170	11,661
Maryland	3,564,627	1,810,058	2,280,231	2,040,690	183,820	90.8	2,431,446	1,179,136	488,730	35.5	9,800	222,970	6.3	334,901	914,478
Massachusetts	6,597,100	3,350,474	4,200,967	3,620,889	98,359	67.6	4,694,815	2,929,059	1,588,358	41.0		313,670	4.6	47,152	1,249,487
Michigan	[illegible]	6,452,568	12,336,753	11,269,771	380,200	490.3	6,756,734	1,330,627	5,367,203	247.9	19,400	487,226	24.5	116,430	217,939
Minnesota	[illegible]	[illegible]	12,727,520	9,673,333	2,756,603	1,332.2	2,957,995	880,181	1,903,508	216.3	64,220	702,065	40.7	133,535	457,375
Mississippi	6,970,675	3,540,227	8,073,765	4,364,463	820,235	473.0	3,837,419	1,809,872	1,462,473	208.1	60,631	776,653	49.3	143,788	460,866
Missouri	12,180,306	6,173,740	11,560,362	10,047,170	689,561	943.8	5,682,707	1,604,956	3,817,898	450.1	245,950	1,666,261	60.1	232,230	
Montana	7,459,746	3,789,734	9,396,341	7,102,183	2,189,133	897.3	1,304,064	63,540	1,118,507	96.6	147,641	203,306	29.9	121,384	56,738
Nebraska	7,823,961	3,964,364	10,124,912	7,766,597	1,263,400	853.6	2,756,165	21,644	2,383,925	159.7		112,536	17.0	44,620	198,502
Nevada	4,545,317	2,302,356	5,569,952	4,263,527	1,208,851	532.7	1,083,897	216,818	804,330	175.3	52,327	224,137	15.6	23,249	62,479
New Hampshire	1,903,839	969,462	2,354,103	1,809,280	449,896	62.7	504,101	29,000	468,508	14.5	13,044		.4	58,515	51,058
New Jersey	6,346,039	3,220,879	5,363,742	4,891,560	138,352	61.4	3,104,136	1,295,764	1,473,052	22.1		812,020	2.1	158,615	737,455
New Mexico	5,792,935	2,941,700	7,478,122	5,555,578	1,598,756	672.9	1,089,970	36,931	1,050,748	95.9	12,633	183,963	1.1	77,794	108,232
New York	22,330,101	11,327,921	24,139,758	19,340,340	1,415,479	402.1	15,212,881	2,514,309	9,030,332	413.3	74,732	238,050	7.7	400,720	644,061
North Carolina	9,522,293	4,840,941	10,828,792	7,997,214	1,746,315	1,061.5	3,006,699	927,348	1,955,421	242.4	182,655	548,144	32.8	415,077	931,061
North Dakota	5,804,448	2,938,967	5,436,728	5,055,278	454,581	1,607.2	926,427	325,115	463,333	243.2	331,561	651,058	131.7	92,493	1,369,396
Ohio	15,484,592	7,865,012	17,011,982	15,026,171	856,625	594.5	6,284,657	370,463	5,335,716	165.4		107,300	6.5	87,958	1,514,871
Oklahoma	9,216,798	4,635,180	9,725,336	8,414,407	907,677	653.1	4,085,897	792,103	2,910,290	135.8	6,016	296,985	14.0	4,272	570,229
Oregon	6,106,896	3,097,814	7,318,249	5,316,229	877,871	381.6	2,314,336	188,715	1,377,371	83.7	518	80,000	.2	101,434	162,572
Pennsylvania	18,891,004	9,590,788	19,883,931	16,945,385	2,153,200	777.7	8,255,684	1,777,929	6,176,930	281.2	2,126	430,893	7.9	165,564	829,715
Rhode Island	1,998,708	1,014,572	2,142,381	1,858,334	204,739	66.7	710,175	79,740	614,156	16.9		36,315	1.4	60,634	158,863
South Carolina	5,459,165	2,770,954	5,080,044	4,646,088	365,578	391.7	2,462,517	735,422	1,675,694	229.9	27,225	66,990	2.1	50,430	662,692
South Dakota	6,011,479	3,047,643	6,205,513	5,046,355	668,338	1,103.5	2,100,519	678,409	1,372,984	361.5	40,456	362,719	40.4	246,258	643,602
Tennessee	8,492,619	4,302,991	9,440,710	7,692,903	1,007,766	378.9	3,041,605	647,892	2,297,311	98.5	20,090	420,530	7.8	131,734	577,383
Texas	24,244,024	12,291,253	26,579,948	22,965,929	2,413,912	2,168.4	9,248,040	954,287	7,907,205	530.3	52,140	1,143,107	66.7	271,668	827,030
Utah	4,194,708	2,132,691	5,469,792	3,926,218	946,763	512.9	1,538,328	260,153	1,030,350	88.7		17,000	1.1	8,337	138,577
Vermont	1,867,573	948,007	2,467,174	1,806,908	387,121	116.6	573,768	26,801	510,540	22.1	4,042	43,110	.9	29,821	7,236
Virginia	7,416,757	3,765,387	8,323,716	6,644,620	1,090,583	433.4	2,804,093	558,166	1,971,201	149.2	161,555	507,740	27.9	52,416	195,864
Washington	6,115,867	3,106,412	7,036,158	5,832,732	1,127,179	259.5	2,214,757	281,291	1,805,387	42.9		137,968	.3	1,845	35,878
West Virginia	4,474,234	2,280,335	4,249,980	3,738,906	387,201	148.5	1,655,705	671,325	934,380	49.5	56,511	142,561	7.9	7,492	766,192
Wisconsin	9,724,881	4,941,837	10,718,068	9,052,904	1,184,352	480.6	3,937,931	532,063	3,173,755	133.1	82,664	408,632	7.6	57,250	169,097
Wyoming	4,501,327	2,287,712	5,125,126	4,123,788	817,355	719.2	1,707,858	363,973	1,316,601	312.1		84,735	5.2	13,566	69,021
District of Columbia	1,918,469	973,842	2,038,295	1,668,009	370,286	16.9	643,229	250,164	393,065	2.7		75,395	.6	295	135,097
Hawaii	1,871,062	949,778	1,007,238	704,442		24.2	1,430,997	1,126,855	99,424	20.8	20,973	345,645	6.0	18,793	504,709
TOTALS	394,000,000	200,000,000	424,155,312	345,064,988	45,439,500	26,004.8	170,845,754	41,523,397	114,215,941	7,880.9	2,516,601	17,531,538	876.3	4,895,014	22,813,021

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BUREAU OF PUBLIC ROADS

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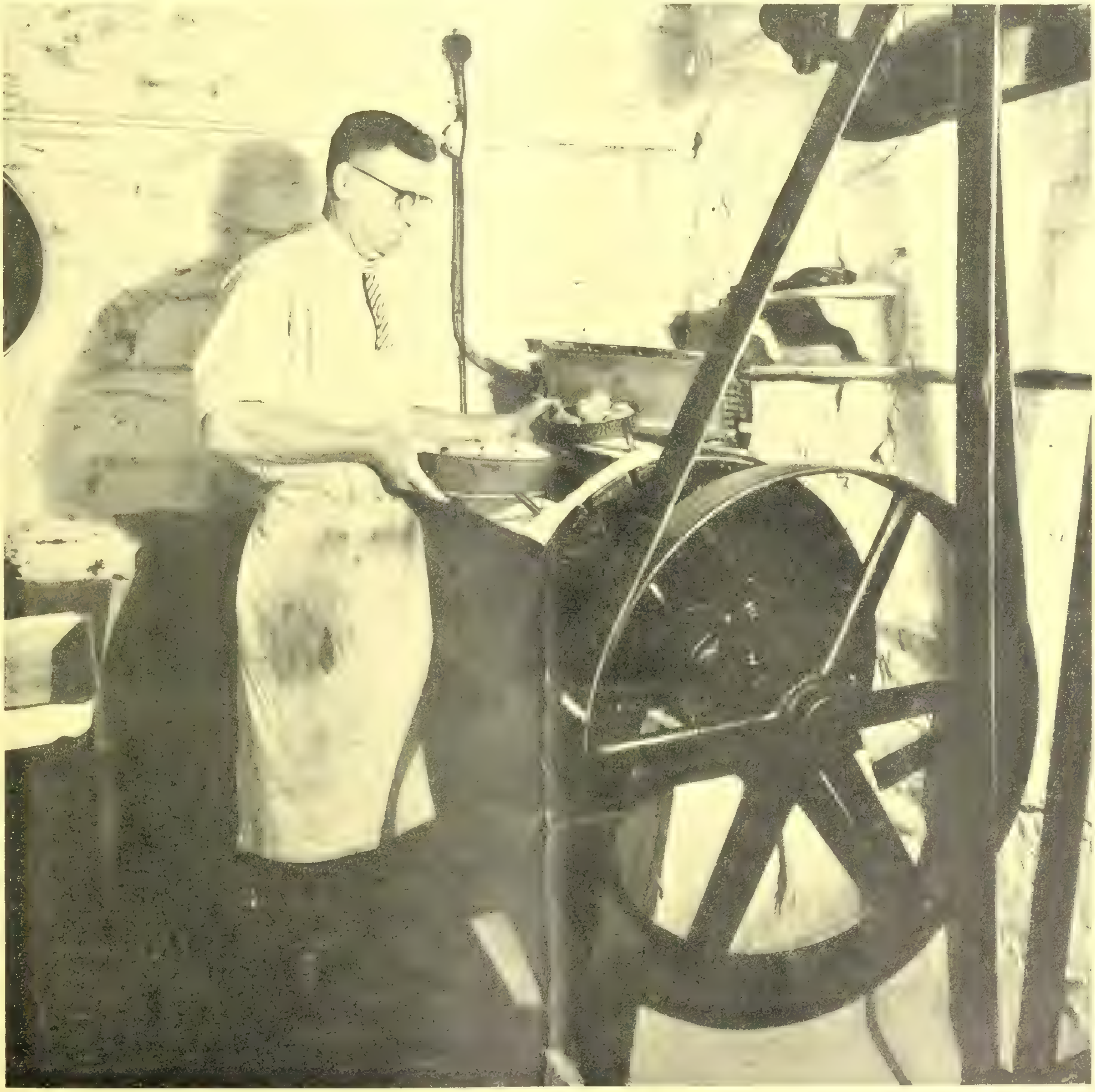

THE LOS ANGELES ABRASION MACHINE

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 16, No. 7 September 1935

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

THE LOS ANGELES ABRASION MACHINE FOR DETERMINING THE QUALITY OF COARSE AGGREGATE

Reported by D. O. WOOLF, Associate Materials Engineer and, D. G. RUNNER, Assistant Materials Engineer, Division of Tests, U. S. Bureau of Public Roads

DURING the past few years there has been a tendency on the part of highway engineers to examine rather critically a number of the time-honored tests for road materials with a view to ascertaining the accuracy with which they measure the ability of materials to meet present-day service requirements.

Two such tests, the standard Deval abrasion test,[1] and the standard toughness test,[2] have been used for many years to determine the quality of ledge rock. The Deval test has been modified by the American Society for Testing Materials to serve as a test for gravel as well as for ledge rock. This modified Deval test for use in testing graded samples of rounded gravel was adopted tentatively in 1928.[3] The American Association of State Highway Officials has also modified the original Deval test for the purpose of testing light-weight materials such as slag.[4]

DEVAL TEST UNSATISFACTORY IN SEVERAL RESPECTS

These modifications, while necessary in order to adapt the Deval test to such materials as gravel and slag, also made necessary the use of entirely different test limits for the various materials even when they were intended for the same service. An illustration of this trend is found in the current specification of one of the State highway departments. For grade A coarse aggregate for concrete that department allows a maximum wear of 6 percent for limestone, 15 percent for blast-furnace slag, and 12 percent for rounded gravel. These requirements are intended to result in the use of aggregates of comparable quality. The differences are necessary because the modified tests give results differing from those given by the standard Deval test on ledge rock of comparable quality. This situation is unfortunate because of the apparent inconsistency which results from the use of different test limits for materials that are to meet the same service requirements.

Criticism is frequently made of the comparatively small range in values given by the Deval test for rock of the quality ordinarily used in road construction. The Deval test is essentially an abrasion test rather than an impact test; for this reason certain types of materials that are very low in toughness, even though they are quite hard, will show relatively low abrasion losses in this test. Certain granitic materials fall in this class. Such materials are frequently reported as giving unsatisfactory results in service, even though their percentages of wear by the Deval test may be quite low.

The standard toughness test has also been subjected to considerable criticism recently, much of which has been directed at the accuracy of the test method itself. Attention has been called to variations in results reported by different laboratories on apparently identical materials. A study of the problem indicates that the trouble is caused by the flattening of the spherical end of the plunger of the testing machine through use, with the resultant tendency to give higher values. Most of the test data upon which many of the State specifications for toughness are based were obtained before the necessity for rigidly controlling this variable was appreciated; hence the condition of the testing machine has assumed considerable importance in the acceptance or rejection of materials. The condition of the testing machine is rendered all the more important by the fact that many rocks are borderline materials from the standpoint of toughness, and even a small variation in test results may mean the difference between acceptance and rejection.

The realization of these and other weaknesses in the present standard tests caused the bureau to investigate the possibilities of the so-called "Los Angeles rattler" test used by the State of California as an acceptance test for coarse aggregates.

THE LOS ANGELES ABRASION TEST DESCRIBED

A number of years ago a machine for determining the abrasive resistance of aggregates was developed by the engineers of the city of Los Angeles, Calif.[5] The method developed is radically different from the standard Deval abrasion test in that the test charge is caused to drop instead of to slide or roll, and also in that an abrasive charge and a sample composed of graded sizes of particles are used. A test run of 500 revolutions is used instead of the 10,000 revolutions required in the Deval test, thus greatly reducing the time required for making the test. In 1927 the California State highway laboratory began a study of the Los Angeles abrasion machine to determine its suitability for use as a substitute for the Deval machine. The machine and test method were apparently found to be satisfactory for in that year the Los Angeles test method was adopted by the State as a standard method. Some changes in the method as originally proposed were made, the latest (1930) test method being as follows:[6]

> The machine used in the test consists of a cylindrical drum 28 inches in diameter and 20 inches in length, mounted longitudinally on a horizontal shaft, and having a shelf 4 inches wide extending from end to end on the inside.
>
> The drum is charged with 14 cubical blocks of cast iron having rounded corners and edges and weighing a total of 5,000 grams, along with 5,000 grams of rock, which is graded as follows:

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[1] Method D 2-33, American Society for Testing Materials Book of Standards, Part II, 1933.

[2] Method D 3-18, American Society for Testing Materials Book of Standards, Part II, 1933.

[3] Tentative Method D 289-28T, American Society for Testing Materials Book of Tentative Standards, 1934.

[4] Method T-3, Standard Specifications for Highway Materials and Methods of Sampling and Testing, American Association of State Highway Officials, 1935.

[5] Selection of Rock and Gravel for Highway Construction, by C. L. McKesson, California Highways, vol. 3, no. 4, April 1926.

[6] From an unpublished report of California Division of Highways, Sacramento, Calif., dated June 13, 1930.

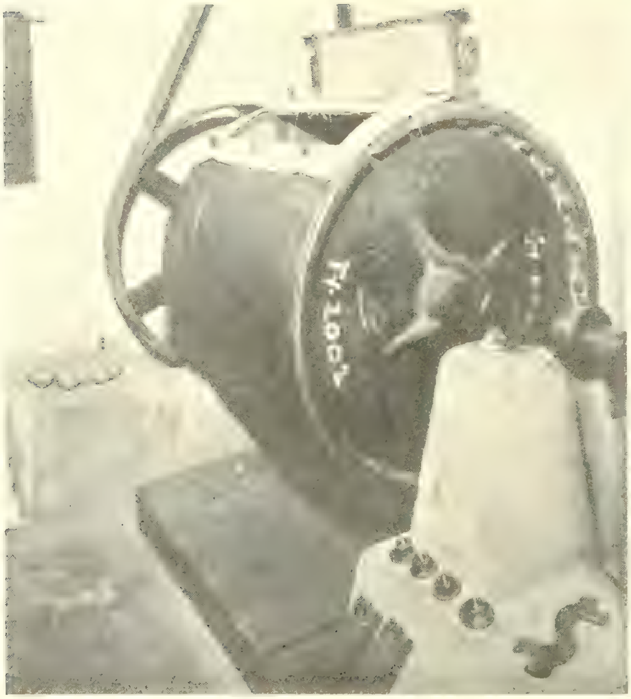

Figure 1.—The Los Angeles Abrasion Machine Showing Cover and Abrasive Charge.

Screen size	Total percent passing
1½ inch	100
1¼ inch	80
1 inch	60
¾ inch	40
½ inch	0

After charging, the drum is revolved 100 revolutions and 500 revolutions at a rate of between 30 and 33 revolutions per minute. The result is reported as the percent of wear at 100 and 500 revolutions. At the present time the wear is considered that portion of the sample which, after test, will pass a 10-mesh sieve having a clear opening of 0.065 inch (no. 12 U. S. Standard).

In its report the California Division of Highways cites certain advantages possessed by this method of testing as follows:

> The Los Angeles rattler test is decidedly more suitable for determining the hardness and toughness of rock and the amount of soft material than any test or group of tests studied. Its advantages are pointed out as follows:
>
> (*a*) The nature of the treatment is severe, bringing out weaknesses not shown by any one of the other tests studied.
>
> (*b*) It is adapted for testing both crushed and gravel aggregates.
>
> (*c*) It requires very little time for performance.
>
> (*d*) It is not affected materially by changes in volume of aggregate due to specific gravity because of the size of cylinders in which the test is made.
>
> (*e*) It eliminates a large amount of the personal equation which enters into some of the other tests.

A study of the test method was undertaken by the bureau to determine whether the conclusions reached by California can be applied to tests covering a wider range of materials. A Los Angeles abrasion machine was constructed according to plans furnished by the California Division of Highways. This machine is shown in figure 1. The shelf which picks up the charge is mounted on the removable cover. This cover was originally fastened on by two bolts at each end. A few tests showed that the cover sprang at the center, allowing dust to escape, and to prevent this the cover is now fastened by two heavy bars, curved to fit the drum and fitting over stud bolts projecting from the drum. The gasket consists of four thicknesses of heavy canvas firmly sewed together.

Test samples of rock, gravel, and slag were obtained from various parts of the country, largely from commercial producers. Where possible samples of both ledge rock and crushed material were obtained. The producers were requested to furnish crushed and ledge rock of the same quality, and as far as could be observed this was done. These samples represented practically all types of rock and gravel that are used for road building. Although only three samples of slag were tested they represent the type of blast-furance slag (70 to 85 pounds per cubic foot) most widely used in highway construction.

BALLS FOUND TO BE MOST SUITABLE AS AN ABRASIVE CHARGE

Prior to the principal series of tests, a preliminary study was made to determine the possibility of substituting balls for the cubical shot used by California. The procedure followed by California required an abrasive charge of fourteen 1½-inch cast-iron cubes. It was recalled that in the standardization work on the brick rattler, abrasive charges of both cubes and balls were used, and that the balls were finally adopted.[7] The cast-iron balls proposed for use in the Los Angeles machine are the same as the small balls used in the brick-rattler machine, and have a nominal diameter of 1⅞ inches and an initial weight of about 431 grams. Since 12 new balls weigh about 5,170 grams, the stock of used balls from the brick rattler was inspected, and 12 balls were selected whose total weight was 5,000±5 grams.

To insure representative results in the preliminary series of tests, one sample of each of the three materials—rock, gravel, and slag—was selected for test and at least nine samples of each material were tested with each type of abrasive charge. Determinations of the percentage of wear were made at the end of 100 and 500 revolutions. After 100 revolutions the material was taken from the machine, sieved on a no. 12 sieve, and the particles were brushed free from adhering dust. All of the material retained on this sieve was then weighed.

The entire charge, including the dust, was replaced in the machine. The test was resumed for an additional 400 revolutions and the amount passing the no. 12 sieve was again determined. The results of these tests are shown in table 1. It will be observed that in every instance the balls caused a greater loss in abrasion than the cubes. The greater weight per unit of area of the ball, together with the delivery of impact at a single point, caused greater loss in the test than the edges and corners of the cube.

Besides producing more severe action on the test specimen, the abrasive charge of balls gives slightly more concordant results. Tests with the ball abrasive charge show an average deviation of 3.4 percent in the loss at 500 revolutions, while the corresponding average deviation for the cubes is 5.5 percent. More concordant results were obtained at 500 revolutions than at 100.

The cubes were found to lose weight at a greater rate than the balls. This required constant adjustment o the cube abrasive charge and possibly affected the abrasive loss. The balls lost very little weight after the

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[7] A Study of the Rattler Test for Paving Brick, by M. W. Blair and Edward Orton Jr., Proceedings, American Society for Testing Materials, Vol. 11, 1911.

TABLE 1.—*Comparison of cubes and balls as abrasive charges in Los Angeles machine*

Sample no.	Kind of material	Abrasion loss using—			
		Cubes		Balls	
		100 revolutions	500 revolutions	100 revolutions	500 revolutions
		Percent	*Percent*	*Percent*	*Percent*
33265	Slag	8.2	38.3	9.7	[illegible]
33278	Gravel	13.7	52.0	17.7	[illegible]
33279	Basalt rock	1.5	6.1	2.0	9.7

first few tests. This feature, combined with the greater abrasion of the test sample and the more concordant results obtained, shows that balls are preferable for use as the abrasive charge. Furthermore, many laboratories are equipped with the brick rattler machine and presumably have a supply of cast-iron balls of suitable size and weight.

RESULTS OBTAINED BY THE TWO METHODS OF TESTING COMPARED

After deciding to use balls as the abrasive charge, the main portion of the investigation was considered. It was desired to compare the results of the Los Angeles abrasion test with those for the Deval abrasion test and, also, to determine the effect of angularity of particle on the Los Angeles test results. To obtain these data, each sample was tested in the Deval and Los Angeles abrasion machines and toughness tests were made on all suitable samples of rock. The Deval abrasion tests on rock and slag were made in accordance with A. S. T. M. standard method D 2–33, and those on gravel in accordance with A. S. T. M. tentative method D 289–28 T. The tests with the Los Angeles machine were made according to the procedure used by California with the exception that the abrasive charge consisted of twelve 1⅞-inch cast-iron balls weighing 5,000 ± 5 grams. To determine the effects of shape and angularity of particles on the test results, tests were made on commercial crushed rock and hand-broken rock of cubical shape with sharp edges and corners, and also on both rounded and angular particles of gravel and rock.

In preparing the test specimens for the Los Angeles test, the samples of gravel, slag, and rock were separated into the various screen sizes and recombined as shown in table 2.

TABLE 2.—*Gradation of Los Angeles abrasion test samples (grading A)*

[Screens with round openings]

Passing	Retained on—	Weight
Inches	*Inches*	*Grams*
1½	1¼	1,000
1¼	1	1,000
1	¾	1,000
¾	½	2,000
Total		5,000

The results of the standard Deval and the Los Angeles abrasion tests using grading A are given in table 3. Most of the test values given are averages of three or more tests. These values have also been plotted in figure 2 together with curves showing the average relation between the standard and modified Deval tests and the results in the Los Angeles machine. The number of points which depart from the average curves demonstrates that the relations are only very general and do not apply to all types of materials nor to all samples of a given type. This is due mainly to the marked difference in the amount of impact produced in the two tests. Although both tests involve both surface wear and impact, the loss in the Deval test is mainly from surface wear, while that for the Los Angeles test is primarily caused by impact. Marble, for example, has about the same wear in the Deval test as limestone or dolomite, but in the Los Angeles test marble shows a much higher loss than the tougher rocks.

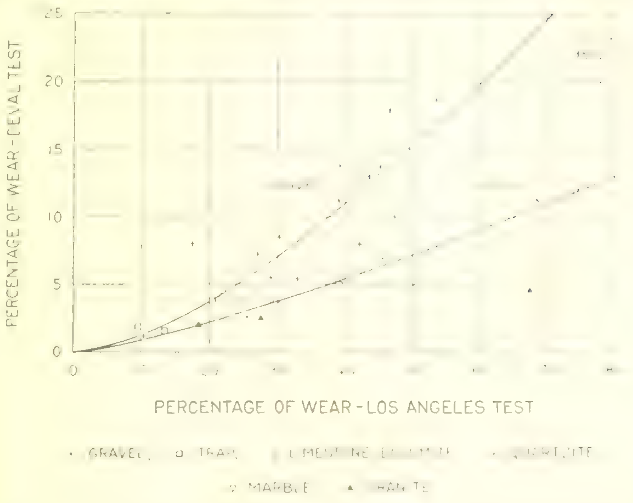

FIGURE 2.—RELATION BETWEEN RESULTS OF TESTS IN DEVAL AND LOS ANGELES MACHINES.

Figure 2 is presented with the knowledge that no definite relation between the losses in the Deval and Los Angeles tests that will apply to all materials can be established. However, the figure will serve to show the approximate change in specification requirements if the Deval test is replaced by the Los Angeles test. For instance, it will be observed that, for an average loss of 50 percent in the Los Angeles test, the average Deval abrasion loss is about 7 percent for rock and 15 percent for gravel. This happens to be approximately the same ratio (1:2) that is used in most specifications with the idea of obtaining materials of comparable quality.

More concordant results are obtained in tests of gravel and crushed rock or slag in the Los Angeles machine than in tests by standard methods using the Deval abrasion machine. Test results in the Los Angeles abrasion machine show a mean variation from the average of 2.7 percent, while those in the Deval machine show a mean variation of 3.9 percent. The difference is not great but it is worthy of notice. It was observed that the speed of operation of the Los Angeles abrasion machine had a great effect on the loss during the test and it was found advisable to equip the motor with a speed control. Each test run was timed to insure that a constant speed of rotation had been used.

EFFECT OF SHAPE AND ANGULARITY OF PARTICLE STUDIED

In its report on the Los Angeles abrasion machine the California Division of Highways stated that the test results are not appreciably affected by the shape or angularity of the particles. The results obtained in the tests reported here are not entirely in agreement with the above statement. To investigate this feature samples of Cheat River, Potomac River, and Delaware

TABLE 3.—*Percentage of wear and toughness as determined by abrasion and toughness tests*

[illegible]	[illegible]	Kind of material	Wear by			Toughness
			Deval test	Los Angeles test (500 revolutions)		
				Gravel, crushed rock, slag	Hand broken rock	
			Percent	*Percent*	*Percent*	
[illegible]	Pennsylvania	Slag	7.8	34.8		
[illegible]	[illegible]	Aplite	2.0	18.4	15.9	6
[illegible]	West Virginia	Limestone	3.8	29.2	24.2	6
[illegible]	Ohio	Slag	14.8	46.7		
[illegible]	New Jersey	Gravel	[3] 15.1	49.8		
[illegible]	Oregon	Diorite	5.8	37.0	30.7	5
33270	South Carolina	Biotite granite	2.5	27.7	21.9	12
[illegible]	Wisconsin	Quartzite	2.6	25.6	19.6	12
33272	Kansas	Argillaceous limestone	3.5	30.5	26.4	6
33273	New Jersey	Trap rock	1.5	13.5	8.3	20
[illegible]	Illinois	Dolomite	5.9	28.4	26.1	6
[illegible]	West Virginia	Gravel	[4] 1.1	10.4		
33276	Ohio	Slag	11.8	36.9		
33278	West Virginia	Gravel	[4] 10.0	[6] 47.5		
33278	do	do		[7] 59.3		
[illegible]	Massachusetts	Basalt	1.8	9.7	7.0	32
[illegible]	District of Columbia.	Gravel	[4] 8.4	[6] 30.3		
[illegible]	do	do	[8] 17.5	[7] 35.3		
[illegible]	Kansas	Limestone	14.4	43.0		3
[illegible]	do	Gravel	[4] 7.5	17.6		
[illegible]	do	Argillaceous limestone	12.8	42.9		4
[illegible]	Ohio	Dolomite	23.6	98.5		2
34545	do	Gravel	[4] 13.8	39.3		
[illegible]	do	Dolomite	8.2	40.2		4
[illegible]	do	Gravel	[4] 7.2	27.3		
[illegible]	Georgia	Marble	6.2	58.3		5
34672	do	do	5.4	50.4		4
[illegible]	do	do	12.8	72.2		3
[illegible]	do	do	12.0	74.4		5
[illegible]	do	Dolomitic marble	7.2	45.5		5
34676	do	do	5.0	39.2		
[illegible]	Florida	Limestone	6.7	35.6		
[illegible]	Virginia	Gravel	[4] 13.7	45.1		
34701	Maryland	do	[4] 18.6	53.7		
34704	Georgia	Micaceous granite	4.8	67.1		
[illegible]	Virginia	Gravel	[4] 13.0	43.8		
34714	New York	do	[4] 7.6	42.1		
[illegible]	West Virginia	Argillaceous limestone	4.0	23.4		
34717	Ohio	Limestone	4.5	22.0		
[illegible]	do	Dolomite	8.6	37.3		
34723	do	Argillaceous dolomite	3.7	24.1		
[illegible]	Illinois	Gravel	[4] 5.3	33.2		
34732	Ohio	Dolomite	3.9	21.5		
[illegible]	Ohio	Limestone	8.2	62.8		
34734	do	Argillaceous dolomite	3.9	20.8		
34749	Pennsylvania	Gravel	[4] 5.5	[6] 29.3		
[illegible]	do	do	[8] 15.2	[7] 34.6		
34756	Massachusetts	do	[4] 17.9	46.8		

[1] Weight per cubic foot, 80.7 pounds.
[2] Weight per cubic foot, 72.2 pounds.
[3] Grading B, rounded particles only. (See A. S. T. M. Tentative Method D289–28T.)
[4] Grading A, rounded particles only.
[5] Weight per cubic foot, 77.0 pounds.
[6] Rounded particles only.
[7] Angular particles only.
[8] Grading A, angular particles only.

River gravels were carefully hand-picked, and the rounded and angular particles were separated. Tests were made in the Los Angeles abrasion machine with both kinds of particles, and the results obtained are given in table 4.

In the preparation of the Cheat River and Delaware River gravels for use as concrete aggregate the oversize material was crushed. It is quite possible that the majority of the angular particles used in the tests came from this oversize material. Visual inspection, however, failed to show any marked difference in quality between the rounded and angular fragments. The Potomac River gravel sample did not contain crushed material. The angular particles obtained from this material were distributed throughout the entire range of sizes, and had the same petrographic analysis as the rounded particles. The test results for these three gravels indicate that angular particles will give a somewhat higher loss than rounded particles of the same quality.

TABLE 4.—*Percentages of wear on rounded and angular gravel tested in the Los Angeles machine* [1]

Sample no.	Material	Wear on—		Loss of angular particles expressed as a percentage of loss of rounded particles
		Rounded particles	Angular particles	
		Percent	*Percent*	
33278	Cheat River gravel	47.5	59.3	125
33992	Potomac River gravel	30.3	35.3	117
34749 34750	Delaware River gravel	29.3	34.6	118

[1] Each value is the average of at least 3 tests.

Results of tests on hand-broken and crushed rock shown in figure 3 also demonstrate that the shape of the particle exerts a considerable influence on the test result, and show that the partially wedge-shaped fragment of crushed rock has a loss of approximately 120 percent of that for the hand-broken fragments of cubical shape. In the tests of the three gravels, the rounded samples contained a greater proportion of particles that tended toward being spherical and offered more resistance to impact than the samples containing angular particles. It is reasonable to apply the findings from the crushed-rock and hand-broken-rock tests to these tests of gravel due to the difference between the shape of the particles of rounded and angular gravel. On this basis, a sample of angular gravel would be expected to give a loss of approximately 120 percent of that found for a sample of rounded gravel of the same quality. It will be observed that approximately this same ratio was obtained in the tests of the three samples of gravel (see table 4).

Further tests to determine the effect of shape and angularity were made on samples of angular and artifically rounded rock. One large sample of crushed rock and two samples of hand-broken rock were obtained, and a portion of each was run in the Deval abrasion machine until the sharp edges and corners had been worn off. Two test samples were then prepared from each material; one sample contained fragments with sharp edges and corners; and the other was composed of rounded fragments. Each sample was tested in the Los Angeles machine and the results obtained are shown in table 5.

The angular rock shows a slightly higher loss than the rounded rock, but in no instance is the increase in wear similar to that found in the tests of gravel or crushed and hand-broken rock. It is apparent that while the sharpness of edge and corner may have some influence on the loss in the Los Angeles test, the shape of the particle exerts a much greater effect and for most purposes the sharpness of edge and corner may be ignored.

Samples of aggregates that contain large percentages of flat or elongated fragments will show a much higher percentage of wear than materials of equal hardness in which the fragments tend more toward cubical shape. This difference between fragments of different shape indicates that the desire of highway engineers to limit the percentage of flat and elongated particles in aggregates is justified. The relatively small effect of sharpness of edge and corner will permit the use of a single specification limit for crushed stone and for either rounded or angular gravel.

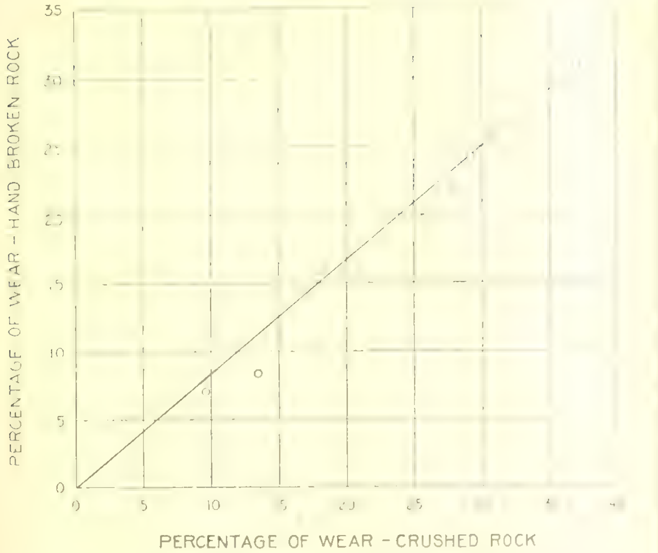

Figure 3.—Relation Between Test Results on Hand-Broken Rock (Cubical Shape) and Crushed Rock (Partially Wedge Shaped) in the Los Angeles Machine.

Table 5.—*Percentages of wear on rounded and angular rock tested in the Los Angeles machine*

Sample number	Material	Wear on[1]		Loss of angular particles expressed as a percentage of loss of rounded particles
		Rounded particles	Angular particles	
		Percent	*Percent*	
34549	Crushed limestone	31.4	33.4	106
34631	Hand-broken sandstone	62.8	64.4	103
	Hand-broken limestone	22.4	23.9	107

[1] Each value is the average of 3 tests.

COMPARISON OF LOSSES AT 100 AND 500 REVOLUTIONS WILL INDICATE PRESENCE OF SOFT ROCK

The method of test used by California requires the determination of the percentage of wear after both 100 and 500 revolutions of the Los Angeles abrasion machine. The determination after 100 revolutions is expected to be useful in determining if soft particles are present in the material. In this connection it was desired to determine if a sample of uniform composition shows a straight-line relation between loss and number of revolutions. Table 1 shows the results of preliminary tests made with cast-iron balls. Figure 4 presents the relation between the length of test and the percentage of loss. It will be seen that for materials 1 and 2 the percentage of loss varies directly with the number of revolutions. Material 3, however, is of nonuniform hardness since the percentage of loss at 100 revolutions is proportionately greater than that at 500 revolutions.

Results of tests to determine the effect of known amounts of soft rock in the sample are shown in table 6 and figures 5 and 6. A hard limestone of uniform composition was used as the base material, and soft rock of varying amounts and sizes was added to it to determine the effect on percentage of wear.

In the first series of tests the amount of soft rock in each sample was held constant at 10 percent of the total weight of the sample while the size of the fragments of soft rock was varied. Tests were made with the soft rock contained entirely in each separate size and also with the soft rock distributed in size from 1½ to ½ inch in the same proportions as is specified for the total sample. Determinations of the percentage of wear were made at 100 and 500 revolutions. As shown in figure 5, the loss at 100 revolutions is affected slightly by the size of the soft rock fragments, the loss increasing

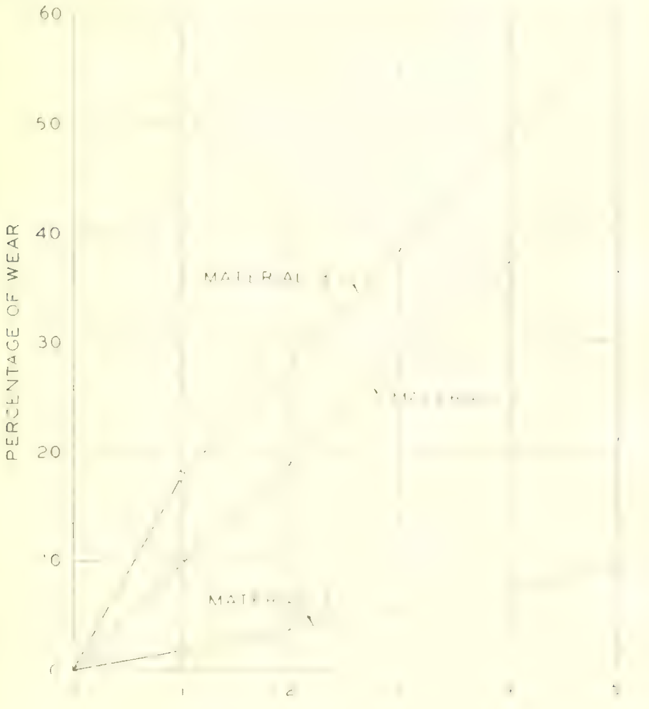

Figure 4.—Relation Between Length of Test and Percentage of Wear, Showing Effect of Soft Particles in Material.

Table 6.—*Percentages of wear for different sizes and amounts of hard and soft rock*

FIRST SERIES

Composition of sample		Classification of soft rock		Wear at—	
Hard rock	Soft rock	Type	Size	100 revolutions	500 revolutions
Percent	*Percent*		*Inches*	*Percent*	*Percent*
90	10	Dolomite	[illegible]	11.2	40.3
90	10	do	[illegible]	12.1	40.2
90	10	do	[illegible]	13.3	40.2
90	10	do	[illegible]	13.9	40.1
90	10	do	[illegible]	13.0	39.9
90	10	Sandstone	[illegible]	10.1	39.1
90	10	do	[illegible]	10.9	38.9
90	10	do	[illegible]	11.3	39.0
90	10	do	[illegible]	13.1	38.8
90	10	do	[illegible]	11.4	[illegible]

SECOND SERIES

Hard rock	Soft rock	Type	Size	100 revolutions	500 revolutions
100	0	None		8.0	35.7
95	5	Dolomite	[illegible]	10.7	37.2
90	10	do	[illegible]	13.0	39.9
80	20	do	[illegible]	18.0	45.0
0	100	do	[illegible]	41.0	[illegible]
95	5	Sandstone	[illegible]	[illegible]	[illegible]
90	10	do	[illegible]	11.4	[illegible]
80	20	do	[illegible]	14.6	[illegible]
0	100	do	[illegible]	33.6	91.7
95	5	Limestone	[illegible]	8.0	35.4
90	10	do	[illegible]	8.6	37.0
80	20	do	[illegible]	9.0	38.9
0	100	do	[illegible]	12.3	55.4

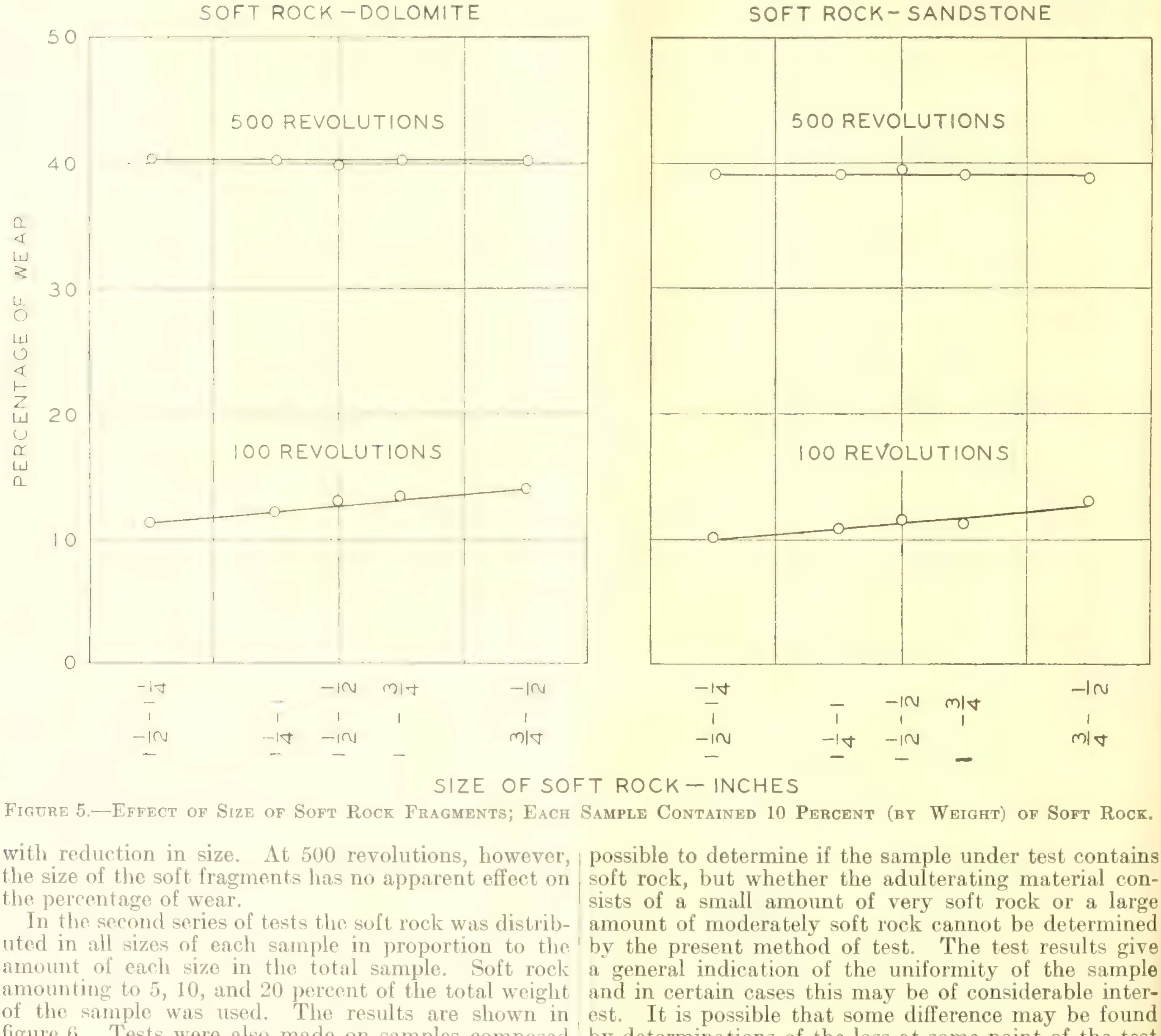

Figure 5.—Effect of Size of Soft Rock Fragments; Each Sample Contained 10 Percent (by Weight) of Soft Rock.

with reduction in size. At 500 revolutions, however, the size of the soft fragments has no apparent effect on the percentage of wear.

In the second series of tests the soft rock was distributed in all sizes of each sample in proportion to the amount of each size in the total sample. Soft rock amounting to 5, 10, and 20 percent of the total weight of the sample was used. The results are shown in figure 6. Tests were also made on samples composed entirely of hard or soft rock. The hard-rock sample gave a practically straight-line relation between percentage of wear and number of revolutions. With the addition of soft rock, the loss at 100 revolutions was more than one-fifth of the loss at 500 revolutions, and the curve assumed a characteristic hump denoting a material of nonuniform hardness. It is of interest to note that the actual loss under test of a mixture of hard and soft rock agrees fairly well with a weighted loss computed from the percentages of wear for the separate materials.

It does not appear possible to determine the percentage of soft rock in a test sample entirely by inspection of the results of the 100- and 500-revolution tests. Figure 6 shows that the difference in slope of the lines from zero to the 100-revolution point, and between the 100- and 500-revolution points, may be used to indicate the relative effect of soft rock in the test sample. This difference in slope increases with increase in the amount of soft rock present. It is possible to determine if the sample under test contains soft rock, but whether the adulterating material consists of a small amount of very soft rock or a large amount of moderately soft rock cannot be determined by the present method of test. The test results give a general indication of the uniformity of the sample and in certain cases this may be of considerable interest. It is possible that some difference may be found by determinations of the loss at some point of the test other than at 100 and 500 revolutions, or that a complete mechanical analysis of the sample after testing will show the character of the adulterating material more clearly.

COMPARISON OF TEST RESULTS WITH SERVICE RECORDS SHOWS ADVANTAGES OF LOS ANGELES TEST METHOD

During the winter of 1933 a number of research organizations studied the problem of devising a satisfactory method of determining the quality of crushed material proposed for use in road surfacing. Reports from a number of different sources stated that the results of the Deval abrasion test bore no relation to the service record of materials used in surface treatment or other types of low-cost road construction. The extensive use of these types of construction necessitated the development of a test that would indicate the suitability of materials for use in this work. One proposed test was to determine the resistance of crushed and graded material to the crushing action of

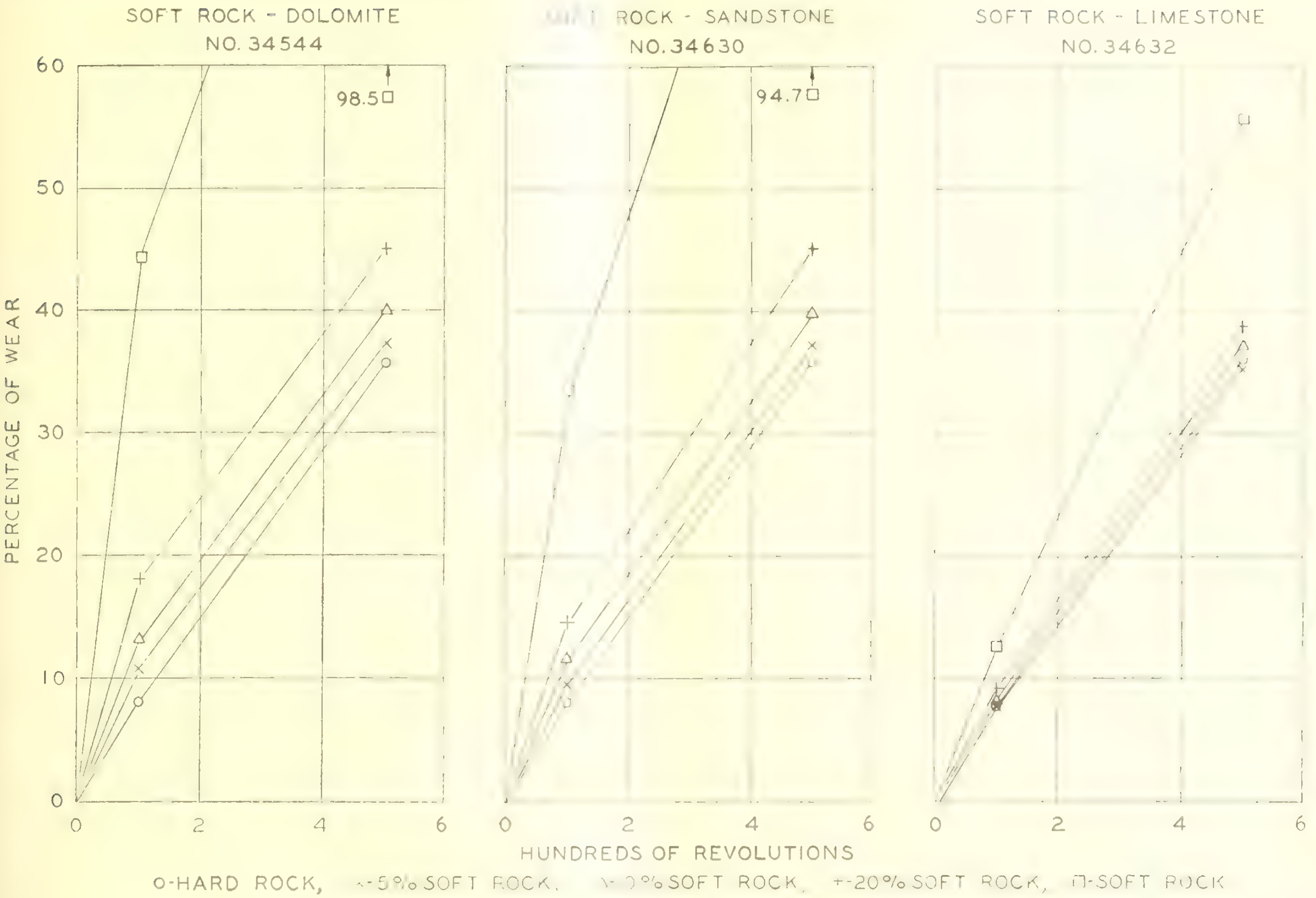

FIGURE 6.—RELATION BETWEEN LENGTH OF TEST AND PERCENTAGE OF WEAR, SHOWING EFFECT OF VARYING AMOUNTS OF SOFT ROCK.

a heavy roller in passing over a thin layer of the material.[8] Although excellent results were obtained by the roller test, the labor and time required rendered it unsuitable as an acceptance test and it was suggested that possibly the less-involved Los Angeles abrasion test could be used to derive information of equal value.

It was realized that in order to cover the range in size of materials used in surface-treatment work provision should be made for testing aggregate having a maximum size of about ¾ inch. In other types of low-cost road improvement the aggregate has a maximum size of about 1½ inches, and it was decided to test samples having gradings suitable for each of these classes of work. In preparing these samples, sieves were used rather than screens since it is the general practice to use square openings in the analysis of this class of materials.

After considerable experimenting, two gradings for the Los Angeles abrasion test were adopted that were believed to be suitable for testing practically any size of material used in bituminous or concrete pavements. It was found that if the amount of abrasive charge for the smaller grading was made slightly less than that for the larger grading, the loss for both gradings would be approximately the same. This permits the establishment of a single specification limit for a material irrespective of the grading used in the test. The gradings and abrasive charges finally adopted are given in table 7.

TABLE 7.—*Composition of sample for Los Angeles abrasion test*

GRADING OF MATERIAL

Size of square opening	Grading B	Grading D
	Grams	*Grams*
1½ to 1 inch	1,250	
1 to ¾ inch	1,250	0
¾ to ½ inch	1,250	2,500
½ to ⅜ inch	1,250	2,500
Total	5,000	5,000

ABRASIVE CHARGE

Number of 1⅞-inch balls	12	11
Total weight, grams	5,000±5	4,583±5

Some concern was expressed as to the possibility that with the change from the previously used grading A (round openings) to gradings B and D, the relations established for grading A could not be applied to the other gradings. However, it was found that the losses for grading B were so nearly the same as those for grading A that for all practical purposes the established data could be applied to test results for grading B.

In order to obtain definite information regarding the significance of the Los Angeles abrasion test in terms of service behavior, samples of crushed rock, gravel, and slag that had been used in surface-treatment of roads were obtained from a number of State highway depart-

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[8] A simple and inexpensive machine for this test is described in a summary of research activities by State highway departments in Rock Products, vol. 34, no. 2, pp. 51–57, Jan. 17, 1931. A more elaborate apparatus is described in A Laboratory Service Test for Pavement Materials, by A. T. Goldbeck, J. E. Gray, and L. L. Ludlow, Proceedings of American Society for Testing Materials, vol. 34, Part II, 1934.

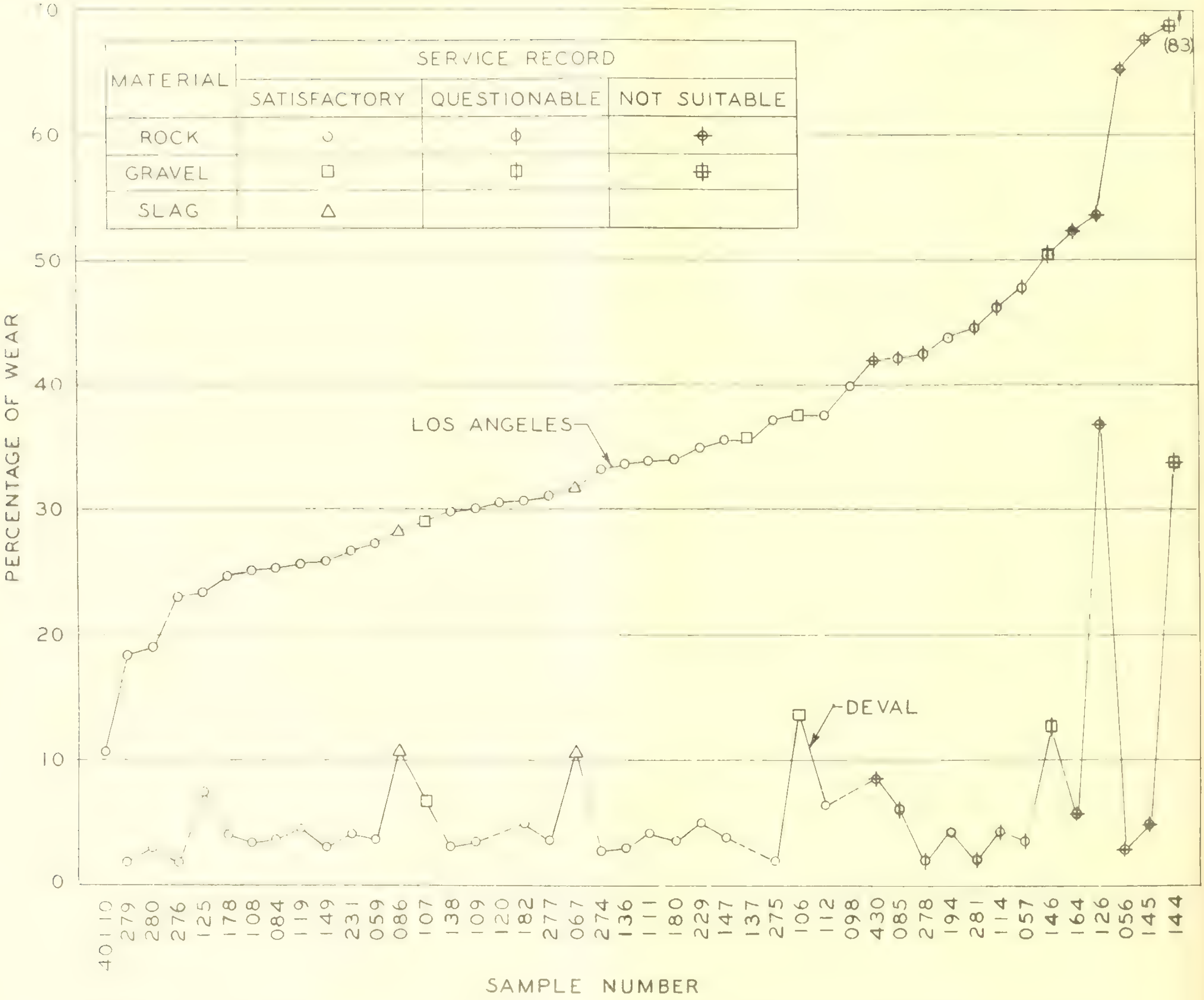

FIGURE 7.—COMPARISON OF LOS ANGELES AND DEVAL ABRASION TEST RESULTS WITH SERVICE RECORD.

ments. Tests of these materials were made in the Los Angeles abrasion machine using gradings A, or when possible using gradings B and D. In the majority of instances, at least three tests were made with each grading. The results of these tests are shown in table 8. In figure 7 a very close agreement is shown between the average results of the Los Angeles abrasion test and the service records of the materials. With the exception of one sample, all materials that were found to be of satisfactory quality in service show losses in the Los Angeles abrasion test of 40 percent or less. Materials of questionable suitability show losses between 40 and 50 percent, and, with one exception, materials that had been found to be unsuitable for use had losses of over 50 percent.

No relation was found between the service record and the loss in the Deval abrasion test. Of 10 samples of rock reported as questionable or unsatisfactory, 8 had percentages of wear of 6 or less and would be considered suitable for use under many present specifications. The one sample of gravel that was reported as questionable had a Deval loss of 12.4 percent and would also probably be accepted for use on the basis of present standard methods of testing coarse aggregates. The great difference in the suitability of the Los Angeles and Deval tests in showing clearly the quality of coarse aggregate is well illustrated in figure 7. As an example, samples 40279 and 40281 had almost the same percentage of wear in the Deval test but in the Los Angeles test the latter material had over twice the loss of the former.

These comparisons between losses in the Los Angeles abrasion test and service records were made on materials from 44 different sources. It is believed that the remarkable concordance of the results justifies the tentative establishment of a loss in the Los Angeles abrasion test of 40 percent as an acceptable limit for material that will prove satisfactory for use in surface-treatment work.

The tested samples of both gradings B and D had nearly equal percentages of wear. As shown in figure 8, in only five samples does the loss for one grading differ by more than 3 percent from that for the other. For 3 of these 5 samples, the loss for grading D is the greater, and it is believed that in the crushing operations the softer rock was reduced in size to a greater extent than

TABLE 8.—*Comparison of Los Angeles and Deval abrasion test results with service behavior of materials*

Sample no.	Location	Kind of material	Percentage of wear				Service record
			Deval test	Los Angeles test			
				Grading A	Grading B	Grading D	
			Percent	*Percent*	*Percent*	*Percent*	
40110	Wisconsin.	Altered basalt				[illegible]	[illegible]
40280	Virginia	Argillaceous dolomite.	2.9		17.2	20.9	Do.
40279	____do.	Aplitic granite	1.7		17.4	[illegible]	Do.
40125	Ohio	Argillaceous limestone.	[illegible]		20.2	[illegible]	Do.
40276	Virginia	Amphibolite	1.7		[illegible]	22.8	[illegible]
40178	New York	Argillaceous limestone	3.9		21.8	24.3	[illegible]
40084	Georgia	Dolomite	[illegible]		[illegible]		Do
40108	Wisconsin	do	3.2		[illegible]	[illegible]	Do
40119	Pennsylvania	Quartzite	1.4		[illegible]	[illegible]	Do.
40149	Tennessee	Argillaceous limestone.	3.0		[illegible]	[illegible]	Do
40059	Georgia	Limestone	[illegible]	[illegible]			Do.
40231	New York	Argillaceous limestone.	[illegible]		28.0	[illegible]	Do.
40086	Alabama	Slate	10.5		28.2		Do
40107	Wisconsin	Gravel	[illegible]		29.1	[illegible]	Do.
40109	do	Dolomite	3.3		30.1	[illegible]	Do
40138	Tennessee	Limestone	[illegible]		[illegible]	29.4	Do
40182	New York	Crystalline argillaceous limestone.	4.9			30.6	Do.
40277	Virginia	Argillaceous limestone.	[illegible]		31.1	[illegible]	Do.
40120	Illinois	Dolomite			31.3	[illegible]	Do
40157	Georgia	Slate	10.5	31.6			Do.
40274	Virginia	Granite	2.6		32.7	[illegible]	Do
40180	Michigan	Limestone	3.1		[illegible]	[illegible]	Do
40111	Wisconsin	Dolomite	1.1		34.4	[illegible]	Do
40156	Tennessee	Limestone	2.8		34.6	[illegible]	Do.
40229	New York	Argillaceous limestone	4.9		34.8		Do.
40137	Tennessee	Gravel			[illegible]	37.7	Do
40147	South Carolina	Granite	3.8		[illegible]	[illegible]	Do.
40275	Virginia	do	1.8		36.6	37.6	Do
40106	Wisconsin	Gravel	13.4			37.5	Do
40112	____do.	Argillaceous limestone.	6.3		39.4	35.6	Do.
40098	Oklahoma	Limestone			40.4	[illegible]	Do.
40194	New York	Biotite gneiss	4.2		[illegible]	[illegible]	Do
40085	Georgia	Dolomitic marble	6.0		[illegible]		Questionable
40278	North Carolina	Granite	1.9		41.0	[illegible]	Do
40281	Virginia	do	1.9		41.8	46.9	Do.
40114	Maryland	Dolomitic marble	4.1		47.0	45.4	Do.
40057	Georgia	Granite	[illegible]	47.7			Do.
40146	South Carolina	Gravel	12.4		50.0	[illegible]	Do.
40430	Tennessee	Limestone	[illegible]		41.4	[illegible]	Not suitable.
40161	Michigan	do	5.7		53.0	[illegible]	Do.
40126	Ohio	do	36.8		[illegible]	[illegible]	Do.
40056	Georgia	Granite	2.8	[illegible]			Do.
40145	South Carolina	Gneissoid granite	4.8		67.6		Do.
40144	do	Gravel	33.6		83.0		Do.

the harder rock. This would account for the greater loss of the finer grading. The other two samples, a biotite gneiss and an argillaceous limestone, contained an appreciable percentage of flat fragments. The excessive loss for grading B is attributed to these flat fragments that are found to a greater extent in the larger sizes of the sample. For all samples tested, the average difference between the losses for gradings B and D is only 1.9 percent. It is believed that either grading may be used in acceptance or control tests of coarse aggregates.

CONCLUSIONS

The results of this investigation demonstrate that the Los Angeles abrasion machine is superior to the present standard Deval machine in the following respects:

1. Los Angeles abrasion tests can be made much more rapidly and are more accurate than Deval abrasion tests.

2. Both round and angular particles may be tested with very little difference in percentage of wear due to the degree of angularity.

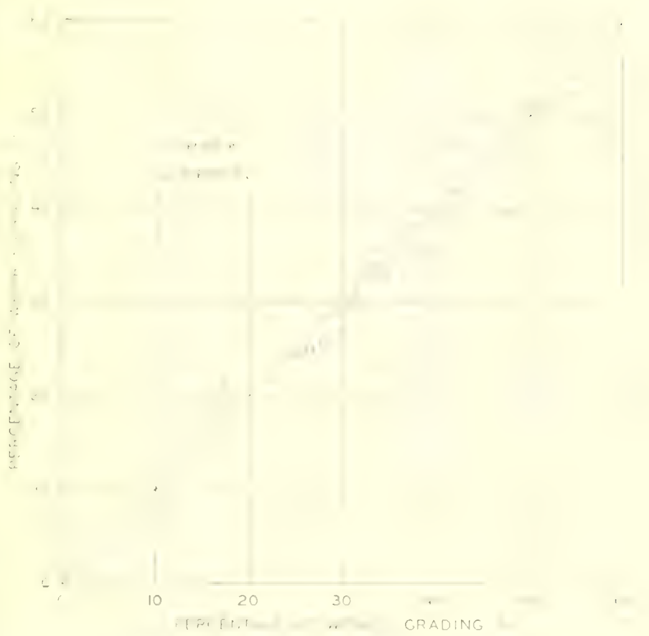

FIGURE 8.—RELATION BETWEEN LOSSES OF GRADINGS B AND D BY LOS ANGELES ABRASION TEST.

3. The Los Angeles abrasion test result is greatly affected by the shape of the particles. Thus the presence of flat or elongated fragments in a sample increases the loss in the Los Angeles test, while in the Deval test these possibly objectionable particles might have little effect on the percentage of wear.

4. The presence of soft or friable rock can be detected with the Los Angeles test but not with the Deval abrasion test.

5. A definite relation seems to exist between the loss in the Los Angeles abrasion test and the service record of materials used in surface treatment of roads. Based on the results available to date, materials having a loss in the Los Angeles abrasion test of 40 percent or less may be expected to furnish satisfactory results when used in surface treatments.

6. Differences in the volume of different test samples due to differences in specific gravity need not be considered due to the relatively large capacity of the Los Angeles abrasion machine.

7. Dust produced in the test does not affect the result as it does in the Deval test.

8. The Los Angeles test is made on material as prepared for use on the project, while the Deval test for rock requires the use of ledge rock that may not represent the material actually used. The two gradings, B and D, proposed for use in the Los Angeles abrasion test, furnish practically the same result, and specification tests may be made using the grading which can most readily be prepared from the material submitted for test.

9. The effect of personal equation in the preparation of the test sample is largely eliminated in the Los Angeles test method.

A disadvantage of the Los Angeles test is that no provision is made for testing ledge rock taken from undeveloped quarries. However, as shown in figure 3, a fairly definite relation exists between samples of crushed and hand-broken rock, and tests could be made on the ledge rock provided the result is corrected to agree with those for the crushed material.

A ROLLER-TESTING MACHINE FOR MEASURING THE STABILITY OF BITUMINOUS MIXTURES

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by **E. L. TARWATER**, Assistant Highway Engineer

DURING recent years numerous laboratory studies have been made of hot asphaltic paving mixtures of both the fine- and coarse-graded types. These studies have been directed primarily towards the development of laboratory tests for predetermining the actual road behavior of various combinations of mineral aggregates and asphaltic materials. The studies have been carried on by various organizations, using different kinds of apparatus and methods of testing. As a result there are now in use several types of tests that appear to be of value in the study and design of bituminous mixtures. All of these tests are designed to measure the probable stability or resistance to displacement under traffic, and a majority of them involve the measurement of resistance to shearing stresses. Two of the better-known tests are the Hubbard-Field and the Skidmore tests.[1]

In the Hubbard-Field test a compressed specimen 2 inches in diameter and 1 inch deep is forced through a 1¾-inch circular opening. The load in pounds required to do this is designated as the stability of the specimen. Specimens are normally tested at a temperature of 60° C. This test is used in the study and design of mixtures of the sheet asphalt type. The Hubbard-Field testing machine is illustrated in figure 1.

The Skidmore test is used for both the fine- and coarse-graded types of mixtures, and the stability is designated as the load in pounds required to shear off the free section of a cylindrical test specimen, part of which is held in a frame or mold. This test is made by applying the load in successive increments. Specimens are tested at a temperature of 60° C. Mixtures containing both fine and coarse aggregate are tested in this manner, the sizes of the test specimens and testing apparatus being increased for the coarse-aggregate mixtures.

Another form of shear test is the extrusion test developed by the Bureau.[2] In this test specimens 2¼ inches by 8 inches by 6 inches deep are formed with a power tamping device and, after being brought to a temperature of 60° C., are placed in a testing mold. A uniformly distributed load is applied to the top of the specimen, causing the mixture to extrude through openings in the bottom and ends of the mold. Stability is designated as the maximum load in pounds supported by the specimen.

The results of this test are influenced by slight variations in the composition of mixtures, and the test was thought to be well adapted to the study of resistance to displacement. However, in testing mixtures containing appreciable amounts of aggregate larger than ½ inch, erratic results were obtained and were attributed to the arching action of the coarser particles. It seemed impossible to eliminate this difficulty without increasing the size of the specimen to unwieldy proportions. It was realized also that the test bore little relation to the action of traffic, and it was thought desirable to develop a method of testing that would more closely simulate actual conditions of use.

ROLLER-STABILITY MACHINE DESCRIBED

With this objective, the bureau designed and constructed a machine in which specimens 8 inches by 4 inches by 2¼ inches deep were subjected to a rolling load causing longitudinal deformation.[3] This roller machine was later rebuilt to eliminate certain objectionable features and as rebuilt was used in the work covered by this report. The machine in its present form is designed to subject the test specimen to the compressive action of smooth metal rollers which pass over it slowly and without impact. The rollers move in one direction under controlled conditions of speed, load, and temperature.

Figure 2 shows a general view of the testing machine. It consists of a rigid base, *A*, carrying the driving motor on one end and a countershaft on the other. In the center of the base there is a pair of vertical guides, *B*. Eleven hollow steel rollers, *C*, 4 inches in diameter and 3 inches long, are arranged between and at equal intervals along the peripheries of two steel disk side plates, *D*. These plates are rigidly fastened to a short horizontal shaft that rotates in bearings mounted on a frame, *E*. These parts constitute the roller assembly and this entire unit is free to move vertically between the guides, *B*. The roller assembly is driven by suitable gearing and may be lifted at will by means of a power-driven elevating mechanism at the top of the guide frame.

The total weight of the roller assembly is 450 pounds, all of which is normally imposed on the test specimen. It is possible, however, to reduce the pressure on the specimen by means of a suspended counterweight attached to the top of the yoke (*E*, fig. 2). This attachment was not on the machine when the photograph was taken. The roller assembly moves at a speed of 2.1 revolutions per minute during tests.

Directly underneath the roller assembly is a rectangular steel tank or water bath, *F*, in which the test specimen is mounted. When the roller assembly is rotated there is a periodic variation of its effective radius (the distance between the surface of the test specimen and the center of the disks, *D*). When one of the rollers is directly below the axis of rotation of the disks this effective radius is a maximum (9.4 inches), and when the midpoint between two of the rollers is directly below this axis the effective radius is a minimum (9.1 inches). In the first position, one roller rests in

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[1] Circular no. 34 of the Asphalt Association.

[2] Emmons and Anderton, A Stability Test for Bituminous Paving Mixtures A. S. T. M. Proc., vol. 25, part 2, p. 346.

[3] Researches on Bituminous Paving Mixtures, by W. J. Emmons. PUBLIC ROADS, vol. 7, no. 10, December 1926.

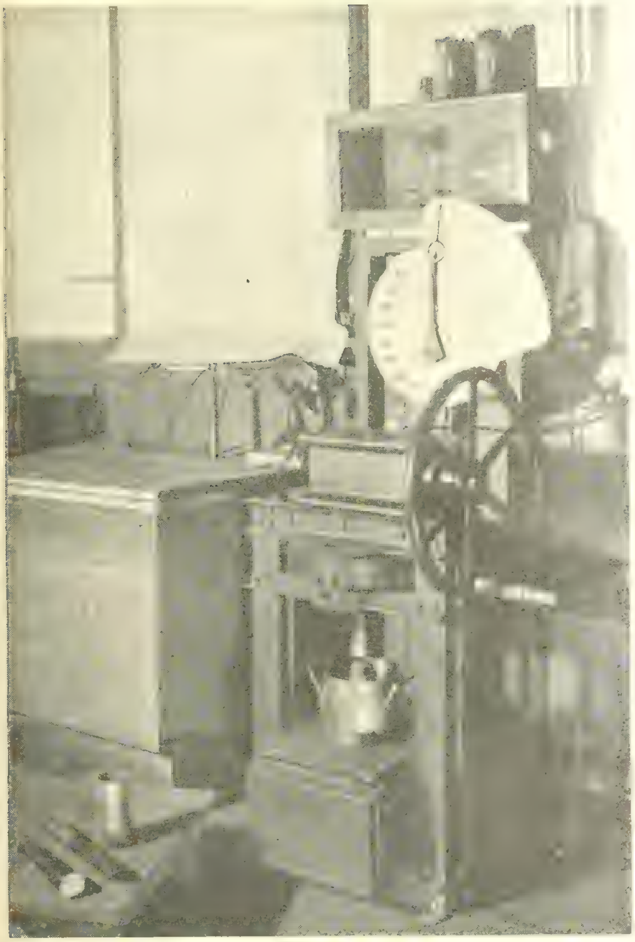

Figure 1.—Hubbard-Field Stability Testing Machine.

the center of the specimen and carries all of the weight, while in the second position two rollers rest on the specimen and each carries half of the imposed weight. If the tank containing the specimen were fixed in elevation, this variation in the effective radius of the roller assembly would cause the entire mass of the assembly to be raised and lowered through a distance of about 0.3 inch 11 times per revolution. In the first machine built the tank and specimen were in a fixed position, and this motion took place and produced an undesirable mpact on the test specimen.

In the rebuilt machine the impact has been eliminated by mounting the specimen bath on four hardened-teel cams (*G*, fig. 2), shaped so that the vertical motion imparted to the specimen by the cams exactly compensates for the changes in effective radius of the roller ssembly. The cams are synchronized with the motion f the rollers through suitable gears. The effectiveness f the arrangement in preventing impact is evidenced y the absence of vertical motion of the roller assembly.

The specimen is confined in an adjustable testing mold that has one end and the top surface open as illustrated in figure 3. Upward deformation at the sides f the specimen is prevented by a section of angle iron (*K*, fig. 4), that is clamped over the mold's edges nd extends ½ inch over the top of the sample at either de, leaving a 3-inch open surface over which the rollers ass. Rotation of the rollers is induced as they pass ver the top surface of the specimen, tending to deform longitudinally through the open end of the mold.

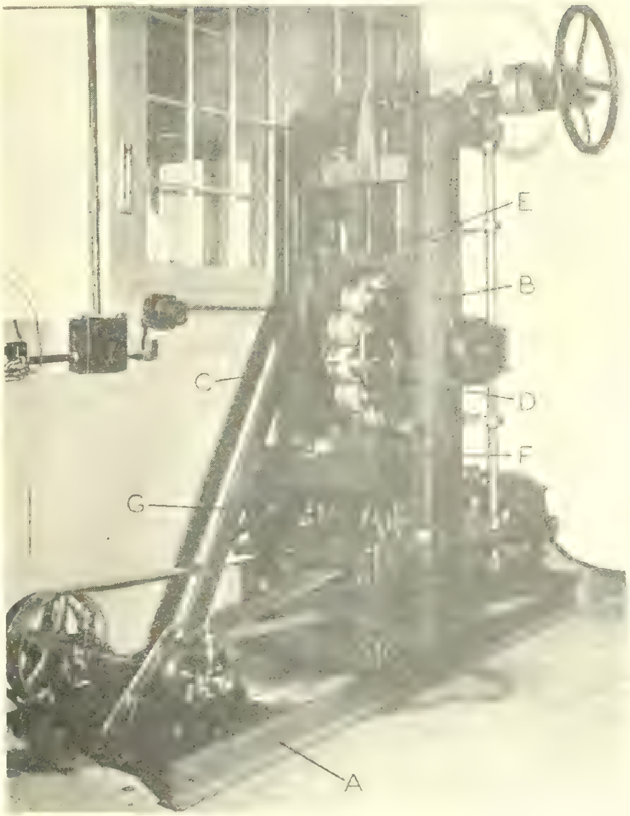

Figure 2.—Roller Stability Testing Machine.

Deformation is measured with an Ames dial (*H*, fig. 4), and a counter, *J*, records the number of roller passages over the specimen. Figure 4 shows the specimen and rollers in testing positions.

LONGITUDINAL DEFORMATION A MEASURE OF STABILITY

The resistance of a test specimen to longitudinal deformation is an indication of its stability. In this study stability was defined as the number of roller passages required to produce a deformation of 0.3 inch. This limit of deformation was adopted after a preliminary investigation showed that for movements in excess of 0.3 inch the relation between the number of roller passages and the amount of deformation became erratic. Figure 5 shows the variations in test results for comparable test specimens. The curves represent test results with three different mixtures from each of which two specimens identical in composition and density were molded. This figure shows that test results on the comparable sheet asphalt specimens, *A* and *B*, and *C* and *D*, were identical up to 0.3 inch deformation, and that considerable variation occurred beyond this point. For the bituminous concrete specimens, *E* and *F*, very close agreement in test results was obtained up to 0.3 inch deformation, while beyond this point an even greater variation occurred than for the sheet-asphalt specimens.

The temperature of the test specimen was held at 60° C during the test. The selection of this temperature was based upon a study made by the Bureau[4] some years ago in which 60° C. was the highest temperature found within a road surface under actual field

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[4] Temperature as a Factor in the Stability of Asphaltic Pavements, by W. J. Emmons and B. A. Anderton. Public Roads, vol. 7, no. 2, April 1926.

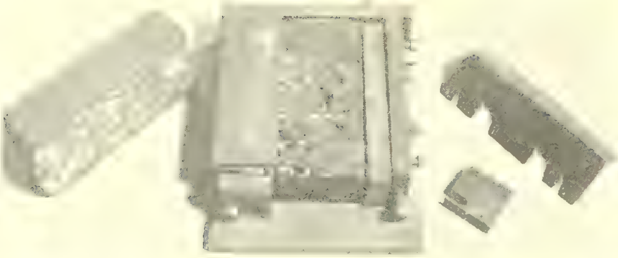

FIGURE 2.—MOLD FOR HOLDING SPECIMENS DURING TEST IN THE ROLLER STABILITY MACHINE.

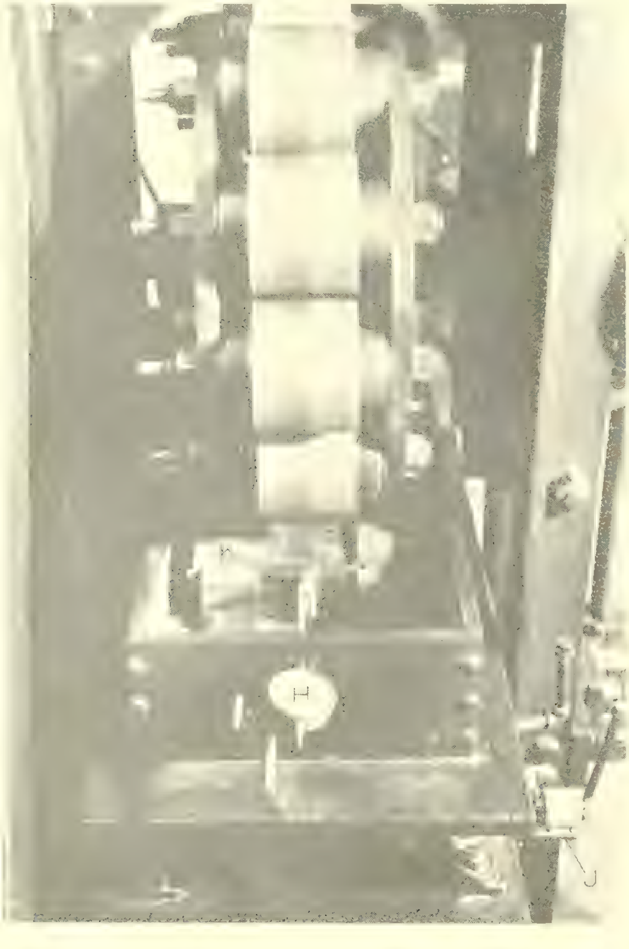

FIGURE 4.—A SPECIMEN IN PLACE READY FOR TESTING.

conditions. This temperature was recorded a number of times, indicating that it was not unusual, and it has generally been used in stability test work by other investigators. The stability values given herein consequently represent the minimum that the mixtures may be expected to possess under normal service conditions.

The power tamping device, formerly used in forming specimens for the extrusion test and for the first roller machine, was discarded in favor of a molding machine in which the specimens are compacted by a rolling load. This machine, illustrated in figure 6, and described in PUBLIC ROADS, vol. 10, no. 2, April 1929, more nearly simulates actual compaction on the road and produces specimens sufficiently uniform in density and of any workable density desired. This machine was used in forming specimens for the roller stability tests, and also in forming specimens from which cores for the Hubbard-Field test were taken.

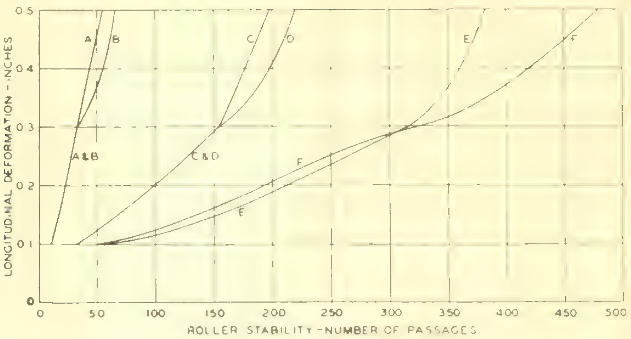

FIGURE 5.—RELATION OF NUMBER OF ROLLER PASSAGES TO LONGITUDINAL DEFORMATION.

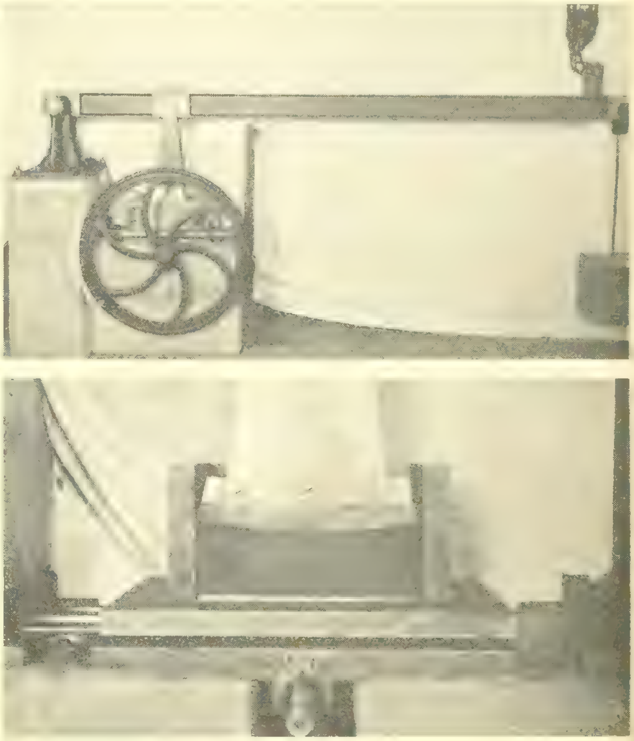

FIGURE 6.—THE UPPER PICTURE IS A GENERAL VIEW OF THE MOLDING MACHINE. THE LOWER PICTURE SHOWS A SHEET-ASPHALT SPECIMEN IN THE MOLDING MACHINE.

The adequacy of any laboratory test for determining the relative stability of paving mixtures is dependent upon its ability to distinguish between mixtures of variable compositions, whether laboratory prepared specimens or sections taken from pavements that have shown different service behaviors. Hubbard and Field have demonstrated that their stability test is quite sensitive to variations in consistency and quantity of asphalt cement, kind and quantity of filler, and character and grading of the sand in sheet asphalt pavements. They have also shown,[5] by tests on cores taken from pavements in use, that the stability values obtained in the laboratory are a measure of the resistance of the surfaces to displacement under traffic. The test as designed by them, or as slightly modified to utilize available laboratory equipment, is widely used as a method of measuring stability.

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[5] Correlation of the Stability Test with the Behavior of Pavements under Traffic. Proc. Fifth Annual Asphalt Paving Conference.

TESTS MADE ON SHEET ASPHALT AND ASPHALTIC CONCRETE MIXTURES

In order to determine the value of the roller stability machine, sheet asphalt mixtures of variable composition were tested for stability in both the roller-stability and the Hubbard-Field machines. The relative stabilities of bituminous-concrete mixtures of variable compositions, both prepared in the laboratory and taken from surfaces under traffic, were also determined with the roller-stability apparatus.

In this investigation the same kinds of materials were used throughout, that is, one asphalt cement, one limestone filler, and one type and grading of sand and coarse aggregate. The coarse aggregate in the bituminous concrete mixtures was a relatively soft limestone and was used for the purpose of determining whether crushing of the aggregate would occur either in molding or in testing specimens. Careful examination of the specimens showed that little or no crushing occurred. The Potomac River sand used was angular to subangular, consisting essentially of quartz, shale, and sandstone, and containing some grains of chert, schist, feldspar, mica, and clay.

The characteristics of the various materials used were as follows:

ASPHALT CEMENT

Specific gravity, 25°/25° C	1. 043
Flash point, °C	285
Penetration, 100 g, 5 sec., 25° C	50
Softening point, ° C	55
Ductility, 25° C., centimeters	110+
Loss on heating, 50 g, 5 hours, 163° C., percent	. 05
Penetration of residue after loss by heating	40
Total bitumen, soluble in CS_2, percent	99. 8
Organic matter insoluble in CS_2, percent	. 1
Inorganic matter insoluble in CS_2, percent	. 1
Total bitumen insoluble in 86° B. naphtha, percent	28. 5

LIMESTONE DUST

Specific gravity	2. 701
Percentage retained on no. 200 sieve	12. 0
Percentage of voids (Bureau vibrator method)	37. 6

CRUSHED LIMESTONE

Passing ¾-inch sieve, retained on ½-inch sieve, percent	52. 5
Passing ½-inch sieve, retained on no. 4 sieve, percent	22. 5
Passing no. 4 sieve, retained on no. 8 sieve, percent	25. 0
Specific gravity	2. 310
Percentage of wear	10. 4
Absorption, percent	6. 56

SAND

Passing no. 10 sieve, retained on no. 20 sieve, percent	7. 6
Passing no. 20 sieve, retained on no. 30 sieve, percent	7. 2
Passing no. 30 sieve, retained on no. 40 sieve, percent	11. 2
Passing no. 40 sieve, retained on no. 50 sieve, percent	17. 0
Passing no. 50 sieve, retained on no. 80 sieve, percent	25. 6
Passing no. 80 sieve, retained on no. 100 sieve, percent	8. 8
Passing no. 100 sieve, retained on no. 200 sieve, percent	15. 2
Passing no. 200 sieve, percent	7. 4
Specific gravity	2. 659
Percentage of voids (Bureau vibrator method)	33. 4

PREPARATION OF SPECIMENS AND METHODS OF TESTING

The proportions of the mixtures used are expressed as percentages by weight of the total and are shown in table 1. In the preparation of the test specimens the aggregates were proportioned by weight and then heated to about 184° C. The hot aggregates were then placed in a mixing pan that was indirectly heated by an oil bath. The asphalt cement, previously heated to about 168° C., was added and the mass mixed with trowels until all particles were uniformly coated. The amount of the mixture needed to make a specimen 2¼ inches thick and of the desired density was then placed in the molding machine form and rolled.

TABLE 1.—*Composition of the mixtures used in the stability determinations*

SHEET ASPHALT MIXTURES

Composition of bituminous mixtures				Composition of mineral aggregates		
Bitumen	Dust	Sand	Stone	Dust	Sand	Stone
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10	0	90	—	0. 0	100. 0	—
10	5	85	—	5. 6	94. 4	—
10	10	80	—	11. 1	88. 9	—
10	15	75	—	16. 7	83. 3	—
10	20	70	—	22. 2	77. 8	—
10	25	65	—	27. 8	72. 2	—
8	15	77	—	16. 3	83. 7	—
10	15	75	—	16. 7	83. 3	—
12	15	73	—	17. 1	82. 9	—

BITUMINOUS-CONCRETE MIXTURES

Bitumen	Dust	Sand	Stone	Dust	Sand	Stone
8	4	78	10	4. 3	84. 8	10. 9
9	4	77	10	4. 4	84. 6	11. 0
10	4	76	10	4. 4	84. 5	11. 1
11	4	75	10	4. 5	84. 3	11. 2
6	4	70	20	4. 2	74. 5	21. 3
7	4	69	20	4. 3	74. 2	21. 5
8	4	68	20	4. 4	73. 9	21. 7
9	4	67	20	4. 4	73. 6	22. 0
5	4	61	30	4. 2	64. 2	31. 6
6	4	60	30	4. 3	63. 8	31. 9
7	4	59	30	4. 3	63. 4	32. 3
8	4	58	30	4. 4	63. 0	32. 6
9	4	57	30	4. 4	62. 6	33. 0
5	4	51	40	4. 2	53. 7	42. 1
6	4	50	40	4. 2	53. 2	42. 6
7	4	49	40	4. 3	52. 7	43. 0
8	4	48	40	4. 3	52. 2	43. 5
5	4	41	50	4. 2	43. 2	52. 6
6	4	40	50	4. 2	42. 6	53. 2
7	4	39	50	4. 3	41. 9	53. 8

The required amount of rolling varied with the composition of the mixture, the load used, and the amount of compaction desired. After rolling the specimen was removed, allowed to cool to room temperature, and its density and voids were determined.

The specimens to be tested in the roller machine were placed in collapsible forms that supported the sides and prevented warping or other deformation. They were then transferred to a constant-temperature water bath at 60° C. and left until they were at a uniform temperature throughout, as determined with a thermometer embedded in a similar specimen prepared for temperature control. The time required to reach this temperature was about 3 hours. The specimens were then transferred to the testing mold and placed in the bath of the roller testing machine, the temperature of which was also maintained at 60° C. The revolving disk carrying the rollers was lowered until its full weight was carried by the specimen. A record was kept of the number of roller passages over the specimen and of the corresponding longitudinal deformations.

RESULTS OBTAINED WITH HUBBARD-FIELD AND ROLLER MACHINES COMPARED

In order to have a uniform basis for comparing the results obtained with the two testing machines, it was felt that the test specimens not only should have similar composition and physical characteristics but also

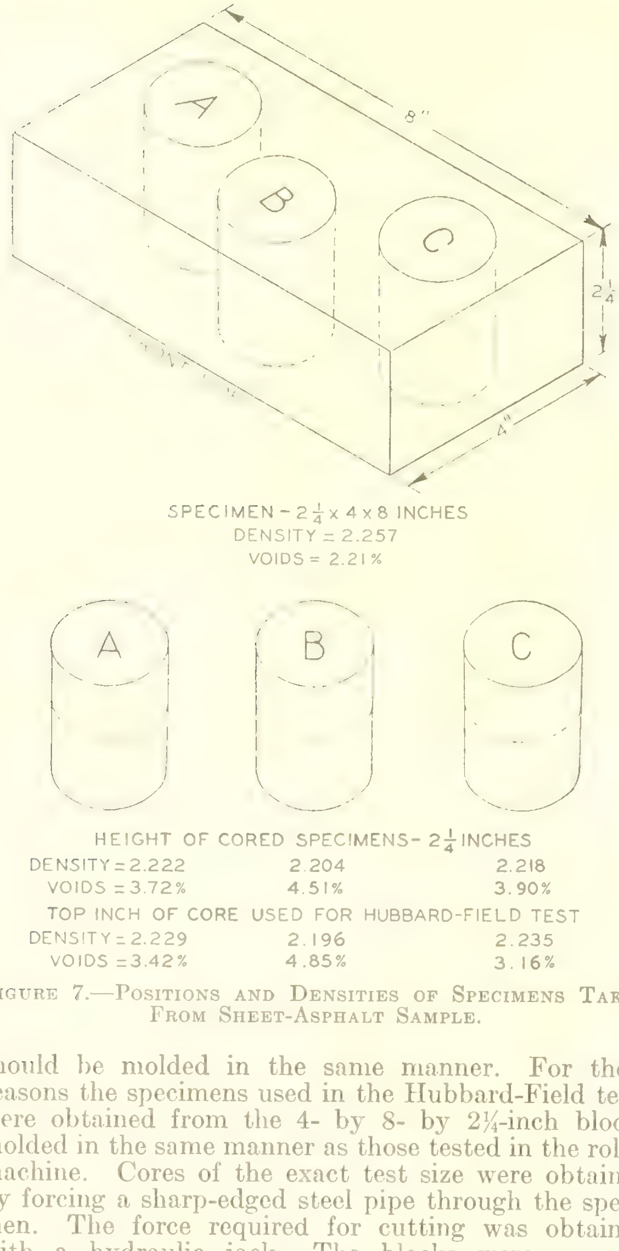
A
B
C
8"
$2\frac{1}{4}$"
4"
SPECIMEN - $2\frac{1}{4}$ x 4 x 8 INCHES
DENSITY = 2.257
VOIDS = 2.21%
A
B
C
HEIGHT OF CORED SPECIMENS - $2\frac{1}{4}$ INCHES
DENSITY = 2.222 2.204 2.218
VOIDS = 3.72% 4.51% 3.90%
TOP INCH OF CORE USED FOR HUBBARD-FIELD TEST
DENSITY = 2.229 2.196 2.235
VOIDS = 3.42% 4.85% 3.16%

Figure 7.—Positions and Densities of Specimens Taken From Sheet-Asphalt Sample.

should be molded in the same manner. For these reasons the specimens used in the Hubbard-Field tests were obtained from the 4- by 8- by 2¼-inch blocks molded in the same manner as those tested in the roller machine. Cores of the exact test size were obtained by forcing a sharp-edged steel pipe through the specimen. The force required for cutting was obtained with a hydraulic jack. The blocks were warmed slightly to facilitate penetration with the minimum of distortion. The top 1 inch of the core was used as the specimen and the average of the test results from the three Hubbard-Field specimens taken from the molded block was reported as a single test result.

Figure 7 shows the relative positions of the cores, *A*, *B*, and *C*, taken from the 8- by 4- by 2¼-inch blocks and also shows the variation in densities and percentages of voids between the Hubbard-Field specimens and the block from which they were cored. This variation is believed to be due to particle disarrangement that occurs along the cut surfaces of the core, since previous work with the molding machine has shown that the 8- by 4- by 2¼-inch blocks are quite uniform in density throughout.[6]

Two series of mixtures of the sheet-asphalt type were used in the comparison of the two machines. In one series the percentage of dust was held constant and the percentages of sand and asphalt cement were varied. In the other series the percentage of asphalt cement was held constant and the percentages of dust and sand were varied. The percentage composition by weight of the mixtures is given in table 1 and the test results are shown in figures 8 and 9.

Figure 8 shows an increase in stability with a decrease in the percentage of voids for all three bitumen contents, the change in stability being least for the mixtures containing 12 percent of bitumen. In this mixture, a change in percentage of voids has a greater effect upon the Hubbard-Field stability than upon the roller stability. With the mixture containing 10 percent of bitumen, however, the reverse appears to be true, while for the mixture containing 8 percent of bitumen the two curves have about the same slope.

Figure 9 shows the effect of percentage of voids on the stability of mixtures containing various percentages of dust. Here, as in figure 8, the general trend of the results is the same for both methods of test. For mixtures containing 15 percent or less of dust the stability increases with a reduction in percentage of voids, while with mixtures containing 20 and 25 percent of dust the stability increases as the percentage of voids increases.

These curves show a marked similarity in the general trend of results obtained by the two methods of test. However, there is no definite mathematical relation between the stabilities determined by the two methods.

ROLLER STABILITY TEST RESULTS FOR ASPHALTIC CONCRETE MIXTURES

Asphaltic-concrete mixtures of the compositions given in table 1 also were tested in the roller machine in the same manner as the sheet-asphalt mixtures. As shown in table 1 the percentage of dust was constant for all asphaltic-concrete mixtures, the principal variables being the amounts of stone and sand used. For each of the five percentages of stone, the asphalt-cement content was varied sufficiently to produce a series of mixtures having a range in plasticity. The test results showing the relation between roller stability and percentage of voids for the different mixtures are plotted in figures 10 and 11, and the effect of the percentage of asphalt cement for varying percentages of voids is shown in figure 12.

As was found for the sheet-asphalt mixtures, an increase in stability occurs as the voids percentages are decreased for a given asphalt-cement content; an increase in stability also occurs for a decrease in asphalt-cement content when the voids percentage is kept constant. These data indicate that the roller machine distinguishes between the factors affecting the stability of asphaltic-concrete mixtures, as well as for sheet-asphalt mixtures.

ACTUAL ROAD DISPLACEMENTS COMPARED WITH ROLLER-STABILITY VALUES

Few data are available for use in correlating actual field behavior with roller stability; however, some tests have been made upon samples from pavements of known behavior. Specimens from the asphaltic-concrete sections of circular track described in Public Roads, vol. 14, no. 11, January 1934, were tested for stability in the roller machine. The analyses of the sections tested are given in table 2, and the results of the test are shown graphically in figure 13. This curve

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[6] A Machine for Molding Laboratory Specimens of Bituminous Paving Mixtures, by J. T. Pauls, Public Roads, vol. 10, no. 2, April 1929.

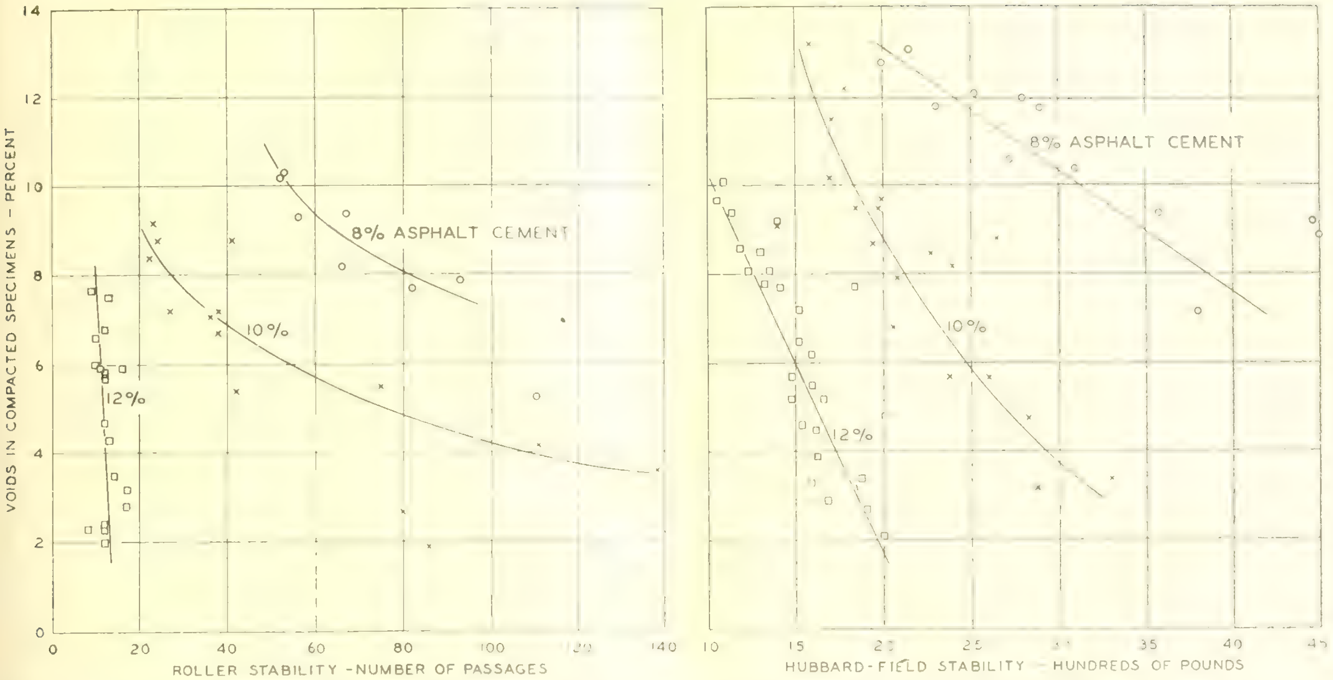
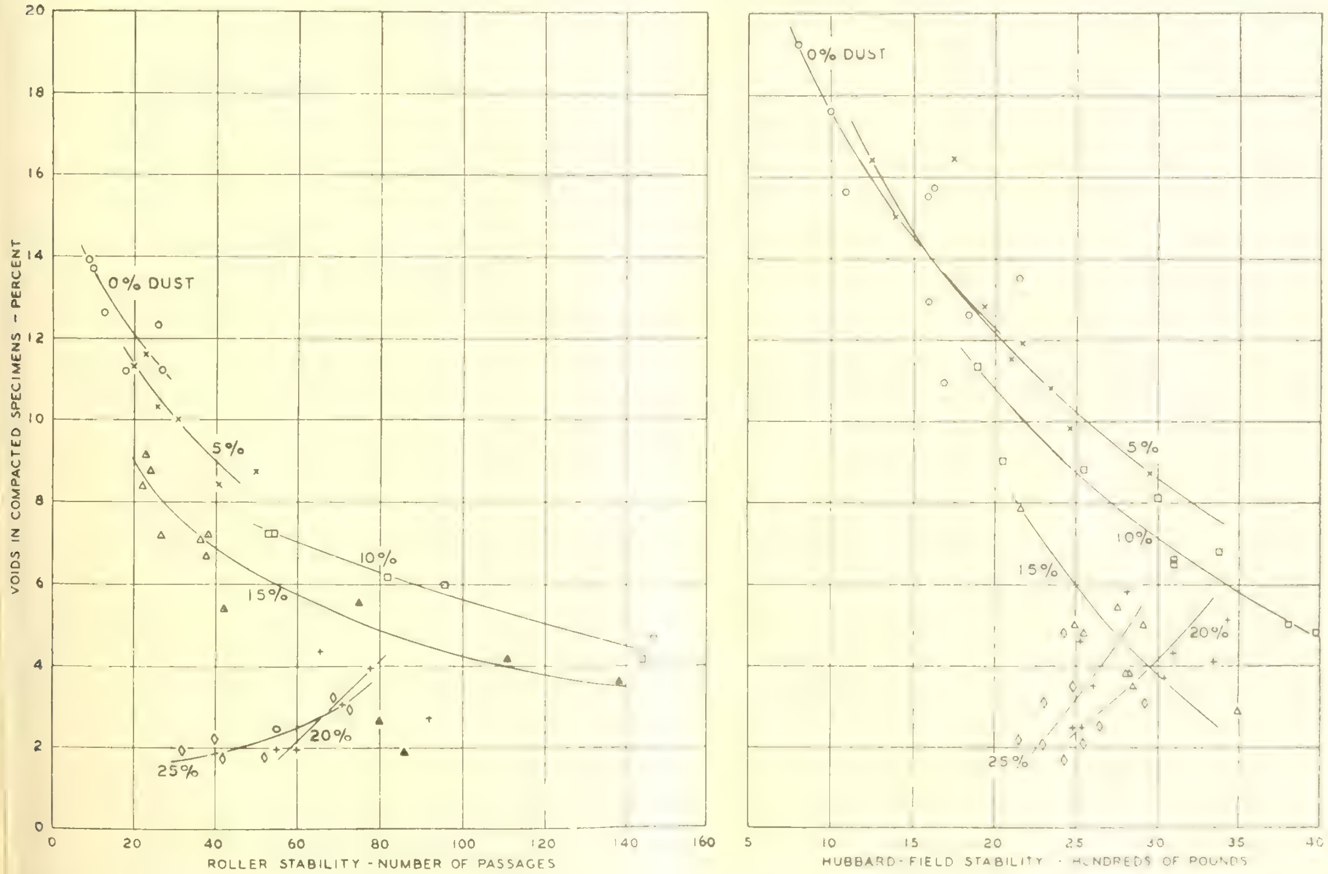


FIGURE 8.—RELATION BETWEEN STABILITY AND PERCENTAGE OF VOIDS IN SHEET-ASPHALT SPECIMENS CONTAINING 15 PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF ASPHALT CEMENT AND SAND.



IGURE 9.—RELATION BETWEEN STABILITY AND PERCENTAGE OF VOIDS IN SHEET-ASPHALT SPECIMENS CONTAINING 10 PERCENT OF ASPHALT CEMENT AND VARIOUS PERCENTAGES OF LIMESTONE DUST AND SAND.

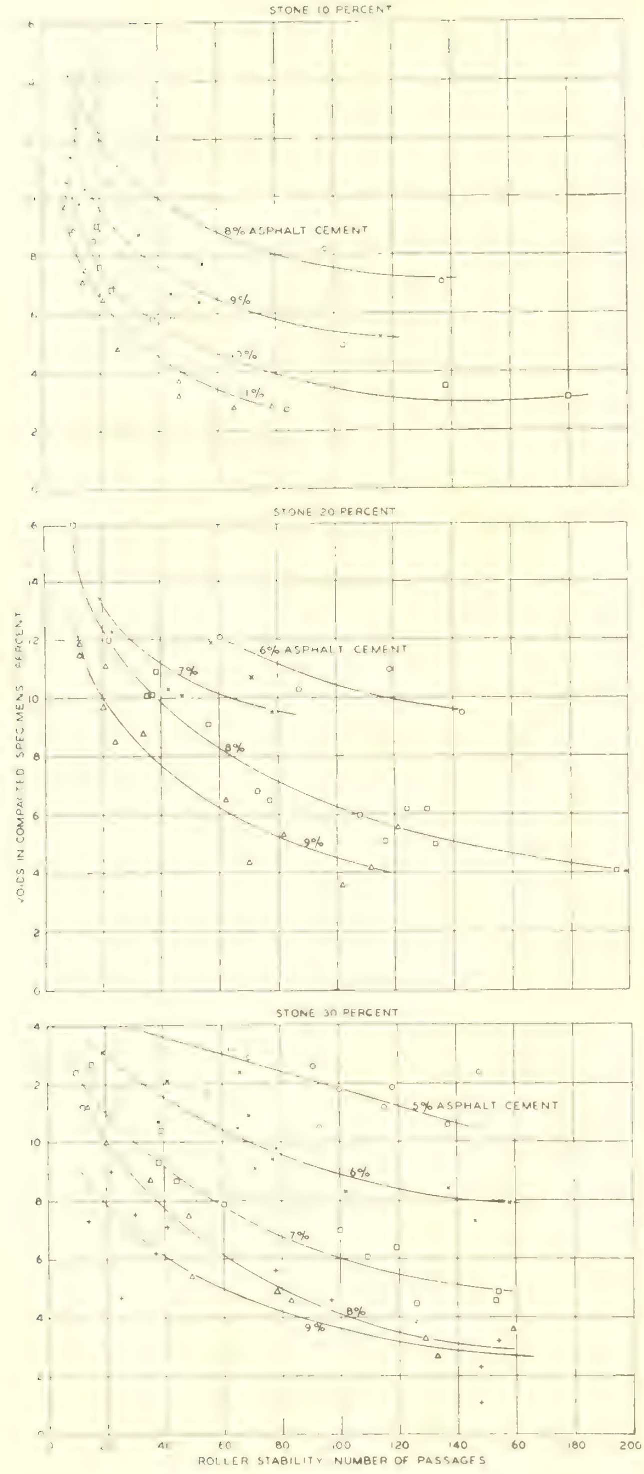


FIGURE 10.—RELATION BETWEEN ROLLER STABILITY AND PERCENTAGE OF VOIDS IN ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

shows longitudinal displacements of the bituminous concretes in inches plotted against roller-stability values. This longitudinal displacement was the total movement of 25 screws spaced 6 inches apart in a radial line on a circular test pavement and was derived by taking half of the total movement of 50 screws in two lines. The sections with the least displacement had the highest roller-stability values.

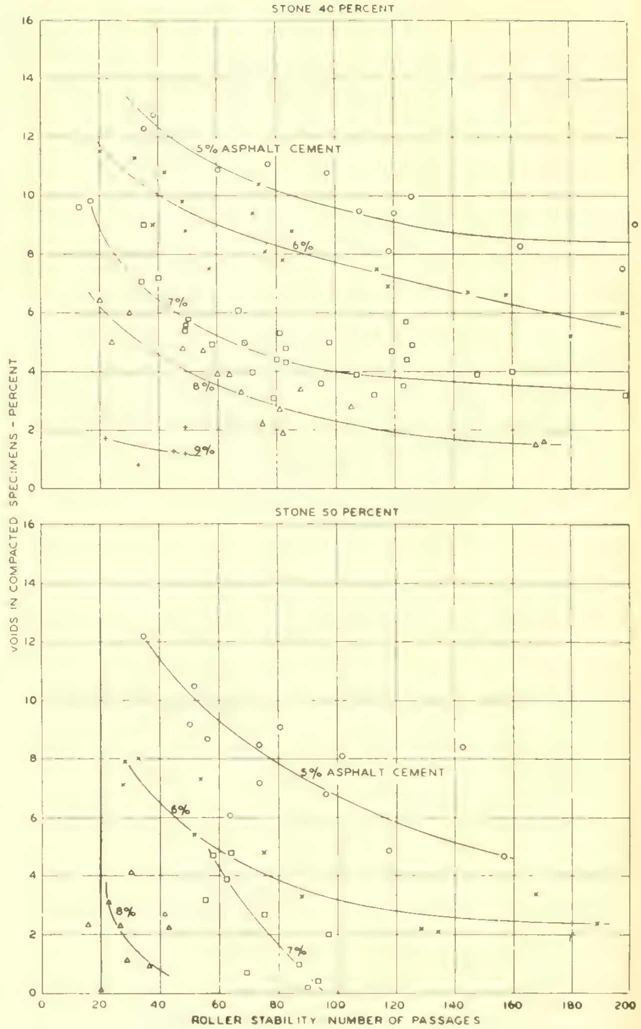
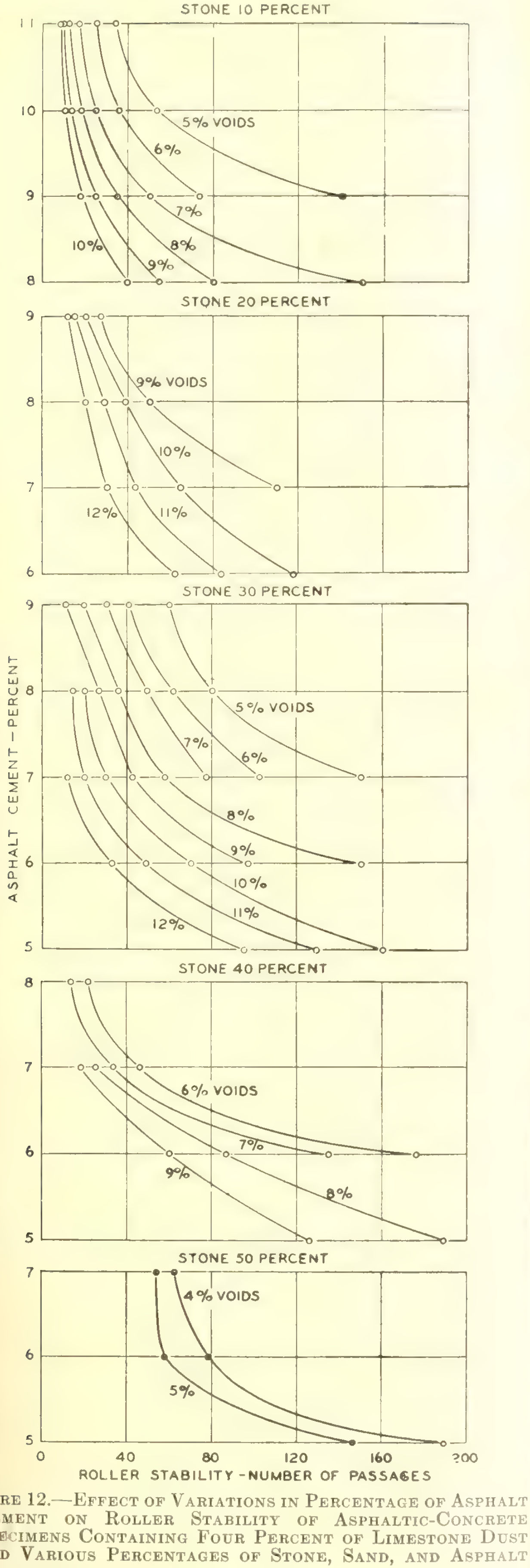


FIGURE 11.—RELATION BETWEEN ROLLER STABILITY AND PERCENTAGE OF VOIDS IN ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

ROLLER STABILITY METHOD PROVES PRACTICABLE

A study of the test data presented shows that, while no constant relation exists between stabilities as measured by the Hubbard-Field and roller-stability machines, both methods show the effects of various percentages of ingredients and voids, factors that influence the stability of sheet asphalt mixtures. Both methods show that variations in a given factor influence stability in the same way. In addition, the roller machine results show the effect of various percentages of ingredients and voids upon the stability of bituminous concrete mixtures, the results being comparable to those obtained on the sheet asphalt mixtures and are in agreement with commonly accepted theories. Although a considerable number of tests on pavements of known behavior will have to be made before roller stability results can be used as a measure of expected service behavior, it appears that the roller machine is a satisfactory device for determining the relative stabilities of both fine- and coarse-graded asphaltic mixtures.

Additional advantages of the roller machine are that specimens of varying depth can be tested and that field specimens can be prepared without apparently disturbing the material within the specimen. This is



IGURE 12.—EFFECT OF VARIATIONS IN PERCENTAGE OF ASPHALT CEMENT ON ROLLER STABILITY OF ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

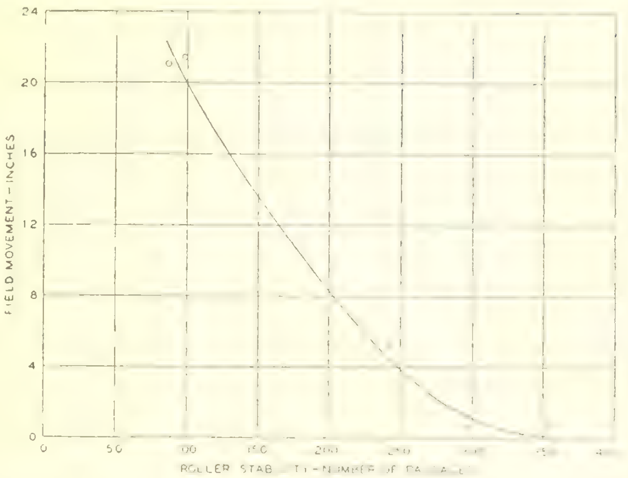


FIGURE 13.—COMPARISON OF FIELD MOVEMENT AND ROLLER STABILITY OF ASPHALTIC-CONCRETE SECTIONS FROM CIRCULAR TRACK.

TABLE 2.—*Laboratory analyses, field movement, and roller stability of sections of pavement from the experimental circular track*

	Section no. —				
	29	30	31	32	33
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Bitumen	4.8	5.8	7.1	7.6	7.3
Passing 1¼-inch screen, retained on 1-inch screen	0.0	4.7	3.6	4.3	2.7
Passing 1-inch screen, retained on ¾-inch screen	14.6	12.7	9.6	10.0	11.8
Passing ¾-inch screen, retained on ½-inch screen	17.0	16.1	11.7	13.9	16.1
Passing ½-inch screen, retained on ¼-inch screen	8.6	10.4	10.9	10.9	9.1
Passing ¼-inch screen [1], retained on no. 10 sieve [2]	3.0	4.8	5.7	5.6	7.0
Passing no. 10 sieve, retained on no. 20 sieve	3.3	3.0	3.7	4.5	4.8
Passing no. 20 sieve, retained on no. 30 sieve	4.3	4.0	4.5	4.6	5.0
Passing no. 30 sieve, retained on no. 40 sieve	3.4	3.0	3.4	3.3	3.3
Passing no. 40 sieve, retained on no. 50 sieve	8.2	6.6	7.2	6.9	6.5
Passing no. 50 sieve, retained on no. 80 sieve	12.0	9.2	10.5	8.7	8.4
Passing no. 80 sieve, retained no. 100 sieve	6.8	5.2	6.2	6.1	4.8
Passing no. 100 sieve, retained on no. 200 sieve	8.5	8.6	9.1	7.6	6.5
Passing no. 200 sieve	5.5	5.9	6.8	6.0	6.7
Total	100.0	100.0	100.0	100.0	100.0
Field movement, inches	0.8	0.5	5.1	21.1	21.5
Maximum movement of single screw, inches	0.2	0.1	1.2	2.9	3.3
Roller stability	355	297	211	88	99

[1] Screens have circular openings. [2] Sieves have square openings.

done by cutting with a carborundum saw that apparently does not displace the material. The effect of slight displacement is lessened since the area of the test specimen is larger than the area subjected to load during the test.

By controlling the weight on the specimen during test, test values can be obtained for the more plastic types of mixture for which a comparison between test and service performances may be desired. It should also be possible to compare test and service performances of the cold-laid or liquefier type of surface.

Since the method of fabricating test specimens in the laboratory simulates the methods of compaction used in actual construction, it is believed that the use of the molding machine for fabrication and the roller machine for testing should furnish satisfactory laboratory evaluation of probable service performance for the various types of bituminous mixtures.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 7,059,832	$ 3,640,038	$ 333,151	388.0	$ 1,649,304	$ 305,142	$ 1,169,295	80.0		$ 210,259	11.8	$ 2,573	$ 417,216
Arizona	3,851,555	1,381,051	5,211,218	3,829,743	681,541	381.6	783,475	15,039	676,061	13.3				10,772	23,459
Arkansas	3,334,167	1,714,000	4,046,186	2,718,557	638,844	185.4	1,686,416	590,256	941,878	81.5		35,901	.2	25,354	97,377
California	7,912,928	3,713,643	11,765,341	7,790,341	841,365	380.9	3,465,799	121,228	2,724,900	67.3		11,203	.5	1,360	136,175
Colorado	3,437,265	2,424,504	5,778,807	3,359,612	2,138,123	280.4	335,342	66,649	230,046	12.4				9,003	335
Connecticut	1,404,213	607,500	1,592,908	1,398,014		30.8	670,946		554,726	7.2				6,193	52,774
Delaware	877,566	461,697	1,343,114	872,988	449,668	48.8	12,315	3,959	8,034					618	3,996
Florida	2,469,370	1,116,600	3,892,506	2,375,111	687,741	147.2	304,595	59,479	218,981	9.2		176,810	2.2	34,780	33,068
Georgia	5,044,592	2,556,745	5,640,255	4,306,527	1,089,849	369.3	1,374,629	585,971	705,634	59.1	$ 6,394	13,417	.3	146,700	741,845
Idaho	2,160,858	1,131,910	2,769,575	2,153,872	511,338	226.4	408,060		397,407	21.7		1,670	.1	7,986	221,495
Illinois	4,408,827	2,408,778	2,833,504	2,558,576	221,193	45.4	3,690,501	1,819,990	1,870,511	61.8		317,074		30,261	
Indiana	5,013,921	2,688,633	4,487,570	4,295,612	53,984	128.1	2,991,811	582,357	2,355,968	151.5	77,951	184,814	1.9	63,004	93,866
Iowa	5,027,830	1,953,361	6,293,748	4,978,830	890,386	374.6	1,204,882	49,000	1,058,290	64.8		13,700			985
Kansas	5,044,802	2,354,131	6,018,170	5,004,734	881,135	655.1	1,545,753	31,530	1,446,430	107.9		26,566	.9	8,676	
Kentucky	3,751,605	1,302,209	3,995,191	3,483,004	257,138	292.7	1,269,207	212,241	927,352	54.7		5,000	1.1	56,360	112,719
Louisiana	2,693,135	1,380,419	2,832,996	2,417,973	93,648	85.1	1,434,550	234,221	1,047,066	27.3	40,941		1.3		239,706
Maine	1,567,012	782,195	2,133,370	1,544,248	559,012	57.2	227,518	5,179	222,325	7.1				17,585	858
Maryland	1,782,263	289,609	1,013,261	888,200	123,550	18.6	933,521	803,850	129,671	19.2				90,213	36,389
Massachusetts	1,101,716	1,582,874	1,586,990	1,048,966	104,788	39.7	995,092	52,687	890,583	17.8				63	587,503
Michigan	6,051,533	3,226,284	6,166,972	5,398,945	402,775	259.4	3,317,075	648,450	2,647,561	142.7		112,825	3.6	4,137	63,123
Minnesota	4,561,011	2,533,733	6,581,228	4,254,660	2,131,650	1,022.0	627,791	247,577	338,500	69.2	30,000	3,773	7.5	28,775	59,809
Mississippi	3,489,337	2,832,182	5,887,700	2,776,095	748,044	308.3	2,645,950	620,984	1,584,553	146.1	23,588	210,437	12.6	68,670	289,148
Missouri	5,237,532	2,890,666	5,295,861	4,462,251	219,487	218.8	3,097,676	775,281	2,105,139	93.3		511,494	12.9		54,545
Montana	4,463,849	2,714,208	6,822,322	4,308,662	1,944,331	601.8	854,682	111,796	734,486	51.3	33,476	6,374	7.3	9,915	29,017
Nebraska	3,914,481	1,982,182	5,673,987	3,889,594	703,347	418.3	1,595,894	21,644	1,267,901	60.8				3,243	10,934
Nevada	2,909,387	1,350,356	3,744,024	2,664,314	1,003,444	391.6	602,129	204,263	336,320	88.7	17,734	2,850	2.6	23,075	7,742
New Hampshire	692,118	465,404	1,081,616	692,119	343,460	20.9	99,431		97,436	2.4					24,508
New Jersey	3,173,019	951,379	2,583,536	2,362,178	29,746	42.3	1,437,526	776,741	564,012	10.3		10,168		34,100	347,453
New Mexico	2,846,648	1,676,769	4,093,988	2,711,206	1,227,755	393.8	433,010		433,010	33.7	93,868		4.2	41,574	16,004
New York	10,465,672	3,673,231	12,889,156	9,648,179	719,730	236.4	6,116,780	567,625	2,777,952	116.2	23,000	4,000	.2	226,868	171,549
North Carolina	4,761,147	1,930,365	5,403,173	3,773,322	522,933	669.1	1,459,741	600,274	790,012	116.9	104,450	223,358	13.2	283,101	334,063
North Dakota	2,902,224	1,469,484	3,853,891	2,717,233	552,406	1,287.2	172,855	34,789	98,642	79.1	71,181	251,989	54.3	79,021	566,446
Ohio	7,277,758	3,539,255	8,378,196	7,036,716	751,074	217.2	2,691,104	225,551	2,290,333	51.2	1,500	191,561	3.1	13,991	306,287
Oklahoma	4,608,399	2,342,590	5,376,532	4,262,946	948,076	351.0	1,645,119	339,780	1,101,318	50.3		146,590	7.9	5,672	146,606
Oregon	3,053,448	1,426,910	3,844,042	2,905,698	520,378	205.8	1,035,973	102,555	866,114	43.4		1,000		45,195	39,417
Pennsylvania	6,641,194	4,554,082	9,242,739	6,494,210	2,269,261	179.8	2,297,256	136,292	2,116,286	41.0	2,126	114,109	3.4	8,566	54,426
Rhode Island	988,230	474,772	1,266,571	988,231	202,547	29.7	262,025		262,025	5.1		3,800			6,400
South Carolina	2,729,583	940,954	2,882,836	2,603,538	214,683	248.4	387,710	62,475	325,235	26.6	21,280	203,659	3.2	42,289	197,378
South Dakota	3,005,739	1,523,821	3,659,851	2,612,580	540,898	662.2	1,155,125	342,408	780,634	155.3	49,729	77,388	10.9	1,023	124,900
Tennessee	4,246,309	2,105,454	5,595,148	4,038,778	863,238	213.8	1,183,105	137,237	949,467	41.2	13,450	183,445	2.0	56,845	109,304
Texas	11,588,643	6,858,253	14,286,253	11,329,744	2,340,779	1,214.5	4,304,129	221,299	3,883,216	320.7	35,806	383,126	25.5	1,794	251,132
Utah	2,367,205	1,066,345	3,172,945	2,322,418	580,525	274.8	471,318	37,000	333,550	28.2		117,000	1.5	7,787	35,271
Vermont	928,184	466,042	1,272,427	912,376	250,743	59.2	221,414		207,151	8.2	4,042	4,307		11,766	3,841
Virginia	3,731,207	1,916,178	4,781,694	3,477,394	917,768	200.2	1,204,310	170,446	883,817	60.8	50,355	45,490	7.2	33,012	69,103
Washington	3,057,934	1,553,206	3,363,220	2,859,191	478,099	117.2	1,375,576	198,743	1,050,156	13.3		6,678			18,274
West Virginia	2,013,405	1,140,167	2,479,211	1,957,832	469,952	90.5	372,973	41,447	328,023	10.7	6,984	76,044	4.5	7,143	266,147
Wisconsin	4,697,518	1,818,970	5,257,273	4,386,938	637,071	245.6	1,520,748	298,603	1,088,097	62.9	7,300	70,839	1.2	4,678	22,963
Wyoming	2,250,663	1,686,368	3,051,863	2,105,140	782,549	584.4	996,922	141,021	829,741	149.0		69,397	1.1	4,502	4,631
District of Columbia															
Hawaii	1,693,344	598,778	1,326,739	952,902		27.3	940,719	681,972	98,893	12.3	20,973	183,992	1.4	37,497	315,893
TOTALS	185,194,099	93,698,168	229,679,536	169,574,996	33,923,203	14,926.8	69,511,382	13,287,027	48,750,728	2,956.7	736,128	4,213,107	211.6	1,595,948	6,806,130

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,960	$ 2,260,951	$ 2,063,926	$ 178,344	58.6	$ 533,590	$ 282,674	$ 250,916	15.5	$ 11,886	$ 170,985	3.9	$ 31,441	$ 464,716
Arizona	756,982	289,673	738,883	622,804	86,475	15.1	322,556	129,322	161,999	.5				4,857	41,199
Arkansas	1,964,534	857,025	2,094,157	1,736,222	255,906	49.8	475,446	100,471	373,470	10.3	101,076	190,076	3.0	26,765	37,572
California	4,213,986	2,219,360	5,438,684	3,849,724	901,933	68.8	2,806,815	356,840	1,084,144	7.2		119,500	3.3	7,422	113,784
Colorado	1,718,633	190,000	1,937,260	1,670,293	170,641	40.0	11,229	11,229		.8				37,111	19,359
Connecticut	802,407	426,500	838,564	802,407	9,362	10.2	193,692		142,521	1.6		261,170	1.8		13,447
Delaware	460,409	230,849	560,829	460,282	92,040	9.2								127	138,809
Florida	1,459,648	501,200	1,887,692	1,443,800	146,700	21.8	119,931		119,931	1.1		149,522	2.2	15,848	85,047
Georgia	2,724,620	1,278,373	2,444,140	2,239,781	170,784	76.8	671,956	266,401	382,267	16.1		31,607	1.2	213,438	693,715
Idaho	1,197,829	321,126	1,225,489	1,150,878	29,138	21.3	193,311		190,428	.6		67,000	2.4	46,951	34,560
Illinois	7,381,910	2,230,350	6,599,641	6,283,943	8,850	66.3	2,358,443	1,071,535	1,286,908	13.8	12,[illegible]	411,443	2.3	14,362	523,149
Indiana	4,287,050	2,243,858	3,901,542	3,475,607	257,159	74.8	2,269,612	656,654	1,612,780	28.3	[illegible]	89,467	[illegible]	55,548	239,462
Iowa	2,614,472	1,[illegible],000	2,964,641	2,403,068	427,495	69.8	874,536	211,305	607,340	12.4				19	[illegible]
Kansas	2,522,401	1,432,949	3,068,016	2,473,483	437,891	47.5	993,451		984,148	9.6	[illegible],918	[illegible]	1.2		
Kentucky	1,927,228	958,599	1,788,387	1,509,834	213,691	39.0	765,528	356,559	385,587	6.6	[illegible],000	[illegible]	4.1	[illegible]	[illegible]
Louisiana	[illegible]	744,560	952,473	793,017	147,468	23.5	1,218,312	896,731	280,141	15.0	10,666	242,681	2.5	8,144	74,271
Maine	[illegible]	[illegible]	1,013,935	910,266	98,154	18.9	430,204	45,122	379,317	4.4				5,038	6,907
Maryland	[illegible]	[illegible],515	429,154	423,149		3.8	1,293,370	467,362		2.2					452,514
Massachusetts	5,007,199	847,600	2,822,356	2,649,581	98,359	16.3	2,498,896	2,328,972	169,924	3.6				28,646	579,317
Michigan	3,500,637	1,613,142	3,696,148	3,148,517	360,400	43.7	1,416,400	310,450	1,093,450	14.1	19,400	140,875	2.6	22,271	18,417
Minnesota	3,719,143	1,421,494	3,710,274	3,129,589	512,534	119.8	1,087,338	515,071	476,784	13.6	2,310	4,758		72,174	427,418
Mississippi	1,744,669	354,022	1,309,979	1,161,617	129,121	40.6	692,091	511,031	110,022	20.3	27,791	12,352	1.7	44,230	102,527
Missouri	4,019,501	919,152	3,286,776	3,156,976	29,290	55.6	1,190,702	712,054	456,911	10.2		432,951	2.7	150,471	
Montana	1,115,962	113,092	1,148,381	1,047,354	58,596	40.3	49,405	35,858	13,547	3.2				32,750	40,949
Nebraska	1,957,240	991,091	2,570,127	1,915,583	612,581	46.5	230,593		230,593	3.3	41,667	39,225	1.9		102,692
Nevada	500,051	100,000	559,805	473,788	56,854	10.8	67,552	26,150	41,402	.6				112	1,744
New Hampshire	740,335	242,465	846,960	668,776	173,847	18.7	53,951		53,741	.5	22,006		.4	49,553	14,877
New Jersey	3,117,921	1,809,500	3,252,404	2,983,109	108,606	23.1	1,053,511	10,297	804,567	5.7		631,441	1.0	124,515	264,787
New Mexico	1,674,158	529,506	1,824,671	1,564,212	249,529	41.9	183,963		183,963	1.1				109,946	96,014
New York	8,255,661	3,961,690	8,793,499	7,695,002	617,300	67.3	3,279,225	392,401	2,731,790	13.0		219,150	.2	168,258	393,850
North Carolina	2,78[illegible],573	1,210,236	2,914,240	2,142,978	750,063	99.8	613,237	21[illegible],174	380,063	11.1		22,458	1.5	22,421	57,651
North Dakota	1,451,112	734,741	1,390,751	1,240,388	142,623	61.4	191,418	146,664	44,754	10.1	40,526	238,430	9.7	23,534	308,934
Ohio	4,3[illegible]5,066	2,359,504	5,229,990	4,236,314	490,826	70.2	1,569,580	93,352	1,370,390	12.9		197,100	1.3	4,020	301,188
Oklahoma	2,304,200	1,171,295	2,527,800	2,109,752	323,001	50.3	751,335	132,161	540,306	8.6		123,251	1.8	2,288	184,737
Oregon	[illegible]	778,728	2,004,562	1,445,150	498,190	38.2	354,145	37,155	[illegible]	4.1	518			43,921	
Pennsylvania	[illegible]	2,397,703	5,863,608	4,630,497	1,033,256	79.1	963,465	101,049	725,150	6.3		234,914	1.3	46,441	404,787
Rhode Island	[illegible]	[illegible],760	651,165	508,370	141,760	8.9								[illegible]	144,000
South Carolina	[illegible]	[illegible]	1,293,76[illegible]	1,233,572	53,000	40.6	343,271	[illegible],504	[illegible]	10.4	9,715	28,37[illegible]	.5		[illegible]
South Dakota	[illegible]	[illegible],211	[illegible],717	1,204,141	119,079	42.4	334,259	100,515	[illegible],744	17.2		154,420	6.9	138,013	[illegible]
Tennessee	[illegible]	[illegible],739	[illegible]	[illegible]	298,739	30.0	[illegible]	165,136	530,318	6.1		84,196	.5		[illegible]
Texas	[illegible]	[illegible]	[illegible]	[illegible]	297,191	[illegible]	[illegible]	686,110	[illegible]	24.7	[illegible],192	[illegible],148	6.7	249,416	[illegible]
Utah	[illegible]	533,173	812,143	649,146	97,066	20.8	645,051	129,130	436,107	13.5				550	
Vermont	[illegible]	240,611	621,407	[illegible],021	114,046	16.6	[illegible]		114,011	2.0		8,129	.4	[illegible]	[illegible]
Virginia	[illegible]	[illegible]	[illegible],087	[illegible],448	417,815	35.0	[illegible]	246,204	438,009	12.2	[illegible]	[illegible]	2.4	[illegible]	[illegible]
Washington	[illegible]	[illegible]	[illegible]	1,374,[illegible]	547,331	[illegible]	[illegible]		[illegible],551	1.9		[illegible]		[illegible]	30,706
West Virginia	[illegible]	[illegible]	[illegible]	[illegible]	28,109	15.6	[illegible]	[illegible]	[illegible],388	[illegible]	28,643	136,097	2.0	61	84,491
Wisconsin	[illegible]	[illegible]	[illegible],482	[illegible],104	[illegible],441	[illegible]	[illegible]	[illegible],457	[illegible],330	7.5		91,921	[illegible]	[illegible]	[illegible],771
Wyoming	[illegible]	[illegible],416	1,104,126	1,098,142	[illegible]	[illegible]	[illegible]	[illegible],068	14,132	[illegible]		7,681		5,116	4,819
District of Columbia	[illegible]	[illegible]	[illegible]	940,446	[illegible],051	6.6									
Hawaii															
TOTALS	[illegible]	[illegible],170	116,743,460	100,730,498	12,968,963	2,129.0	37,753,496	[illegible],264,406	21,256,755	399.0	522,690	5,359,420	78.3	1,96[illegible],847	7,700,044

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3 – PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,961	$ 2,309,887	$ 1,924,006	$ 365,643	161.7	$ 589,857	$ 61,735	$ 528,122	57.6		$ 152,197	3.5	46,711	18,998
Arizona	599,423	971,211	1,146,732	530,962	510,676	96.1	483,106	59,762	407,341	38.2				8,699	53,194
Arkansas	1,449,634	857,024	1,423,425	1,286,905	127,674	185.1	709,585	107,334	600,076	76.1	$ 21,403	120,645	11.8	33,988	8,628
California	3,480,440	1,999,203	4,321,111	3,249,065	342,800	193.1	1,761,849	227,650	1,418,828	49.3		104,000	3.5	3,525	135,575
Colorado	1,718,632	871,502	2,638,722	1,606,032	578,638	275.6	516,993	110,000	292,864	36.2					
Connecticut	659,120	420,868	697,300	659,120	12,889	14.9	222,880		222,880	4.5					185,099
Delaware	481,113	230,449	469,966	277,564	208,650	63.9	224,924	201,248	18,000	7.5				2,301	4,196
Florida	1,306,816	1,043,643	1,630,914	1,279,756	329,467	81.4	693,466		641,918	41.3		49,595	2.8	27,060	22,562
Georgia	2,320,973	1,278,373	1,921,821	1,839,506	53,108	139.0	838,794	393,219	439,575	60.9				88,248	785,691
Idaho	1,121,562	824,450	1,739,651	1,094,530	467,436	201.8	177,969		177,969	22.0		70,000	.4	27,032	109,044
Illinois	5,780,033	4,286,273	4,345,064	4,109,658	180,491	242.9	4,953,938	1,661,465	3,292,473	249.3		456,948	7.1	8,910	352,361
Indiana	731,872	151,472	479,826	417,905	15,004	49.7	369,094	274,972	94,122	50.2				38,996	42,346
Iowa	2,413,358	1,875,000	3,101,720	2,390,624	622,021	513.4	1,255,840	22,027	1,132,425	184.6		5,600	2.3	707	114,955
Kansas	2,522,401	1,330,595	2,757,547	2,473,902	275,787	253.5	1,098,307	47,499	1,044,808	60.6					
Kentucky	1,337,926	1,557,503	2,383,120	1,772,049	468,003	281.1	1,133,012	46,363	1,018,988	128.0		65,505	3.0	13,513	5,006
Louisiana	1,426,879	838,953	1,241,210	1,085,083	143,710	51.6	942,203	337,357	604,846	44.5	3,135	74,211	2.4	1,303	16,186
Maine	842,479	445,012	1,393,835	842,403	429,831	105.7	13,424		13,424	.8				75	1,757
Maryland	891,132	1,067,934	1,053,153	860,196	134,642	72.3	334,765	16,123	318,642	13.8	9,800	176,376	4.1	5,012	438,275
Massachusetts	488,185	920,000	482,233	474,504		15.2	837,333		837,333	20.4				13,681	82,667
Michigan	3,184,057	1,613,142	3,543,656	3,025,292	278,850	222.2	1,417,119	117,227	1,299,892	78.0		34,400	.4	41,538	
Minnesota	2,376,415	1,470,324	3,288,661	2,179,075	913,228	368.2	681,095	133,323	466,017	48.0		70,503	.1	64,017	20,576
Mississippi	1,744,669	354,023	1,325,531	1,309,031	16,500	148.1	514,312	407,501	106,811	38.6		197,261	17.9	28,137	33,451
Missouri	2,923,273	2,363,922	3,395,026	2,686,006	622,066	740.1	1,867,235	235,551	1,586,431	307.1		155,425	14.4	1,716	
Montana	1,859,937	942,434	2,543,443	1,739,224	794,388	305.7	208,613	68,564	140,049	21.2				52,149	7,998
Nebraska	1,957,240	991,091	2,568,346	1,953,891	581,497	441.7	329,975		329,975	51.5		16,708	8.0	3,349	62,911
Nevada	1,136,479	852,000	1,722,864	1,110,208	573,169	208.8	221,262	8,443	212,819	23.7				17,828	66,012
New Hampshire	477,386	261,593	609,099	448,098	111,779	29.9	169,438	29,000	137,633	4.3				287	12,181
New Jersey	55,099	460,000	56,528	55,099		.5	107,525		107,525	1.7		170,412	1.1		182,063
New Mexico	1,272,129	735,425	1,918,265	1,272,129	646,136	296.8	73,332		73,332	2.6					15,956
New York	3,608,768	3,693,000	4,948,637	3,211,646	977,299	160.7	3,380,382	397,122	2,035,040	223.2					30,661
North Carolina	2,380,573	1,700,340	3,127,385	2,246,077	876,509	346.9	908,856	90,285	818,571	82.7				44,211	5,260
North Dakota	1,451,112	734,742	1,372,712	1,267,358	104,721	430.1	154,081	66,752	87,329	30.6	102,670	170,379	96.3	14,332	172,313
Ohio	3,871,148	1,966,253	4,338,414	3,749,696	336,650	349.6	1,277,466	49,860	1,178,223	64.9		92,250	9.6	71,592	359,130
Oklahoma	2,304,199	1,171,295	2,471,681	2,154,542	87,815	282.8	1,164,794	147,071	908,286	50.8		29,343	.3	2,586	145,852
Oregon	1,526,724	892,176	2,276,898	1,494,881	581,851	163.8	252,915	19,526	194,540	10.1				12,317	115,785
Pennsylvania	7,411,822	2,639,003	7,321,815	6,430,741	674,466	593.0	2,772,178	854,159	1,824,964	157.9		115,431	7.0	126,923	24,142
Rhode Island	497,813	254,040	497,631	447,809	39,789	34.2	211,374		211,374	7.1	50,003		3.0		2,876
South Carolina	1,364,791	1,342,000	1,337,533	1,103,131	233,769	141.2	1,318,840	249,891	1,030,599	156.3		70,760	3.6	11,769	6,872
South Dakota	1,502,870	761,911	1,683,466	1,432,735	248,645	485.6	461,370	69,046	392,324	126.3		120,455	28.0	1,090	486
Tennessee	2,123,155	1,075,748	2,202,088	1,805,582	316,213	158.2	668,645	253,399	414,646	28.8	3,663	121,178	4.6	59,912	223,710
Texas	6,012,518	3,638,000	7,736,424	5,969,309	1,297,109	911.5	2,358,413	18,000	2,331,340	135.5		1,000	14.1	25,209	8,551
Utah	1,048,677	533,173	1,627,473	1,041,002	306,173	224.7	263,854		227,000	36.6				7,675	
Vermont	438,880	241,354	785,232	435,360	221,418	51.7	19,034		19,034	1.4				3,520	903
Virginia	1,736,770	893,188	1,894,027	1,555,179	284,724	231.8	513,211	98,691	412,254	52.9	59,804	137,213	14.9	23,097	58,398
Washington	1,080,673	776,603	1,573,597	1,080,673	457,193	113.3	313,146		313,146	11.6					1,265
West Virginia	1,118,559	570,083	900,374	856,050		46.7	647,396	257,170	390,826	31.9		77,781	4.3	5,338	101,477
Wisconsin	2,431,220	1,743,354	2,853,674	2,190,729	476,109	187.1	1,552,806	219,020	1,146,210	49.7		3,553		21,471	117,483
Wyoming	1,125,332	571,928	1,355,150	1,122,742	214,464	213.5	357,466		357,464	63.7				2,590	
District of Columbia	972,024	792,731	1,290,053	971,729	318,324	11.3	263,975		263,975	1.6		75,395	.6	296	135,097
Hawaii	177,718	351,000	178,209	177,718		4.9	150,713		143,867	4.6					207,133
TOTALS	93,272,460	58,416,662	108,300,831	84,704,112	17,857,324	10,902.6	41,775,760	7,359,155	32,881,130	3,030.7	250,483	3,134,524	269.1	958,710	4,543,684

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Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16 1933 (1934 Funds)	Act of June 18 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 11,630,670	$ 7,627,970	$ 877,139	608.3	$ 2,773,252	$ 649,552	$ 1,948,333	133.1	$ 11,886	$ 533,440	19.2	$ 80,726	$ 900,930
Arizona	5,211,960	2,641,935	7,095,833	4,983,509	1,278,692	492.9	1,589,137	204,122	1,245,391	52.0				24,328	117,852
Arkansas	6,746,335	3,428,049	7,563,768	5,741,684	1,022,424	420.2	2,871,447	798,060	1,915,425	167.9	122,484	346,622	15.0	86,107	143,578
California	15,607,354	7,932,206	21,545,339	14,889,130	2,086,098	642.8	8,034,462	705,918	5,227,872	123.8		234,703	7.4	12,306	383,534
Colorado	6,874,530	3,486,006	10,354,789	6,638,538	2,937,403	596.0	864,165	189,878	528,910	49.4				46,114	19,694
Connecticut	2,865,740	1,454,868	3,128,771	2,859,541	22,251	56.0	1,087,518		920,127	13.3		261,170	1.8	6,199	251,320
Delaware	1,819,088	923,395	2,403,909	1,610,834	750,358	121.8	237,738	205,207	26,034	7.5				3,047	147,003
Florida	5,231,834	2,661,343	7,411,112	5,098,667	1,163,909	250.3	1,117,992	59,479	980,830	51.5		375,927	7.2	73,688	140,677
Georgia	10,091,185	5,113,491	10,006,216	8,385,814	1,313,741	585.1	2,885,379	1,251,592	1,527,475	136.1	6,394	51,025	1.6	447,386	2,221,250
Idaho	4,486,249	2,277,486	5,734,715	4,404,280	1,007,912	449.5	779,340		765,804	44.3		138,670	2.9	81,969	365,100
Illinois	17,570,770	8,921,401	13,778,209	12,952,177	410,534	354.6	11,002,882	4,552,990	6,449,892	324.9	12,070	1,185,465	9.3	53,533	875,510
Indiana	10,037,843	5,088,963	8,868,938	8,189,125	326,147	252.7	5,630,517	1,513,978	4,062,871	230.0	177,192	274,271	4.1	157,548	425,674
Iowa	10,055,660	5,118,361	12,360,109	9,772,522	1,939,902	957.7	3,335,308	282,392	2,798,055	261.8		19,300	2.3	746	361,104
Kansas	10,089,604	5,117,675	11,843,733	9,956,779	1,594,743	956.1	3,643,512	75,029	3,485,387	178.0	48,918	37,546	2.2	8,878	
Kentucky	7,517,359	3,818,311	8,166,698	6,764,887	938,832	612.8	3,167,747	615,163	2,331,928	189.3	30,000	256,578	8.1	107,309	290,973
Louisiana	5,828,591	2,963,932	5,074,680	4,296,094	384,825	160.2	3,595,665	1,468,309	1,932,052	86.8	54,742	316,892	6.5	9,447	330,163
Maine	3,369,917	1,711,786	4,541,201	3,296,917	1,086,998	181.8	671,146	50,301	615,066	12.2				22,699	9,522
Maryland	3,564,527	1,810,058	2,495,568	2,171,546	258,191	94.7	2,561,662	1,287,956	448,312	35.2	9,800	176,376	4.1	95,225	927,179
Massachusetts	6,597,100	3,350,474	4,891,578	4,173,052	203,147	71.3	4,331,320	2,381,659	1,897,840	41.9				42,389	1,249,487
Michigan	12,736,227	6,452,568	13,406,776	11,572,754	1,042,025	525.3	6,150,594	1,076,127	5,040,903	234.8	19,400	288,100	6.6	67,946	81,539
Minnesota	10,656,569	5,425,551	13,580,163	9,563,323	3,557,413	1,510.0	2,396,224	895,970	1,281,301	130.8	32,310	79,034	7.6	164,966	507,803
Mississippi	6,978,675	3,540,227	8,523,210	5,246,743	893,665	496.9	3,852,353	1,539,517	1,801,386	205.0	51,379	420,050	32.2	141,037	425,126
Missouri	12,180,306	6,173,740	11,977,662	10,305,233	870,844	1,014.4	6,155,213	1,722,886	4,148,481	410.5		1,099,870	30.1	152,187	54,545
Montana	7,439,748	3,769,734	10,514,145	7,095,240	2,797,315	947.9	1,112,700	216,219	888,081	75.7	33,476	6,374	7.3	94,813	77,964
Nebraska	7,828,961	3,964,364	10,802,460	7,759,068	1,903,424	906.6	2,156,462	21,644	1,828,469	115.6	41,657	55,933	9.8	6,592	176,537
Nevada	4,545,917	2,302,356	6,006,692	4,248,311	1,633,467	611.3	890,943	238,856	590,542	112.9	17,734	2,850	2.6	41,016	75,497
New Hampshire	1,909,839	969,462	2,536,695	1,808,993	629,086	69.5	322,820	29,000	288,810	7.3	22,006		.4	49,840	51,566
New Jersey	6,346,039	3,220,879	5,892,469	5,400,386	138,352	65.9	2,598,562	787,038	1,476,203	17.6		812,020	2.1	158,615	794,303
New Mexico	5,792,935	2,941,700	7,836,924	5,547,547	2,123,420	732.5	690,305		690,305	37.4	93,868		4.2	151,520	127,974
New York	22,330,101	11,327,921	26,631,292	20,554,827	2,314,329	464.4	12,776,387	1,357,148	8,144,382	358.4	23,000	223,150	.4	395,126	646,061
North Carolina	9,522,293	4,840,941	11,444,798	8,162,377	2,149,505	1,115.9	2,981,834	905,732	1,988,646	212.7	104,450	245,816	14.7	349,733	456,975
North Dakota	5,804,448	2,938,967	6,617,353	5,224,979	799,750	1,778.7	518,354	248,205	230,726	119.8	214,377	860,798	160.3	116,887	1,047,693
Ohio	15,484,592	7,865,012	17,946,600	15,024,726	1,578,550	637.0	5,558,150	368,763	4,838,946	129.0	1,500	480,911	13.9	89,603	966,605
Oklahoma	9,216,798	4,685,180	10,376,013	8,527,239	1,358,892	684.1	3,561,248	679,013	2,549,910	109.8		299,184	10.0	10,546	477,195
Oregon	6,106,896	3,097,814	8,125,503	5,845,729	1,600,419	407.8	1,643,033	159,216	1,341,192	57.7	518	1,000		101,434	155,202
Pennsylvania	18,891,004	9,590,788	22,448,162	17,555,448	3,976,984	851.9	6,032,899	1,151,500	4,666,399	205.2	2,126	464,454	11.7	181,930	482,951
Rhode Island	1,998,708	1,014,572	2,415,367	1,944,409	384,096	72.8	473,399		473,399	12.2	50,004	3,800	3.0	4,295	153,276
South Carolina	5,459,165	2,770,454	5,519,131	4,940,242	501,451	430.2	2,055,771	433,870	1,578,001	193.3	30,995	302,791	7.2	54,058	388,710
South Dakota	6,011,479	3,047,643	6,667,034	5,249,456	908,622	1,190.1	1,950,754	511,969	1,406,702	298.8	49,729	352,264	45.9	200,326	380,055
Tennessee	8,492,619	4,302,991	10,082,325	7,802,379	1,478,189	402.0	2,547,204	556,371	1,894,432	76.2	17,113	388,819	7.1	116,756	541,551
Texas	24,244,024	12,291,253	28,156,257	23,003,698	3,935,080	2,262.1	8,484,297	925,409	7,174,011	480.9	37,998	887,274	46.4	276,919	294,888
Utah	4,194,708	2,132,691	5,612,562	4,012,566	983,763	520.4	1,386,222	166,130	996,657	78.3		117,000	1.4	16,011	35,271
Vermont	1,867,573	948,007	2,739,062	1,836,757	586,207	127.5	359,978		340,196	11.6	4,042	12,436	.4	26,774	9,169
Virginia	7,416,757	3,765,387	9,010,808	6,711,020	1,620,310	466.9	2,462,565	514,341	1,734,079	126.0	124,134	249,346	24.5	67,262	161,652
Washington	6,115,867	3,106,412	7,480,683	5,914,727	1,483,222	276.0	1,890,273	198,743	1,564,853	26.8		8,093		2,397	50,244
West Virginia	4,474,234	2,280,335	4,558,280	3,926,871	498,061	155.8	1,487,935	499,195	985,236	49.4	35,626	339,922	10.8	12,541	457,116
Wisconsin	9,724,881	4,941,837	11,485,930	9,086,770	1,900,621	498.2	3,623,391	571,080	2,730,687	120.0	7,300	166,312	3.6	59,731	144,217
Wyoming	4,501,327	2,287,712	5,511,139	4,326,029	999,797	821.4	1,391,171	163,089	1,201,337	215.2		77,078	1.1	12,208	9,500
District of Columbia	1,918,469	973,842	2,417,548	1,918,173	499,375	17.9	263,975		263,975	1.6		75,395	.6	295	135,097
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,091,432	681,972	242,760	16.9	20,973	183,992	1.4	37,497	523,026
TOTALS	394,000,000	200,000,000	456,723,827	355,059,706	64,749,480	27,958.4	149,046,638	32,910,588	103,488,611	6,386.4	1,509,201	12,712,051	559.0	4,520,505	19,049,858

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 8 OCTOBER 1935

FULL-SIZE PAVEMENT SLABS TESTED AT ARLINGTON EXPERIMENT FARM

For sale by the Superintendent of Documents, Washington, D. C - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 16, No. 8 October 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by L. W. TELLER, Senior Engineer of Tests, and EARL C. SUTHERLAND, Associate Highway Engineer[1]

PART 1.—A DESCRIPTION OF THE INVESTIGATION[2]

SINCE 1930, the Bureau of Public Roads has been conducting at the Arlington Experiment Farm, Va., an extensive investigation with the general objective of developing information that will be of assistance in better understanding the structural action of concrete pavement slabs.

More specifically, the research was planned to study the following four main subjects:

1. The effects of loads placed in various ways on pavement slabs of uniform thickness.
2. The "balance of design" or relative economy of typical pavement slab cross-sections.
3. The behavior under load and comparative structural effectiveness of typical longitudinal and transverse joint designs.
4. The effects of temperature conditions and of moisture conditions on the size, shape, and load-carrying ability of pavement slabs.

The study of the effects of loads placed in various ways on slabs of uniform thickness was intended primarily as an experimental verification of the only rational theory of pavement slab stresses thus far advanced, i. e., the Westergaard analysis.[3] The program was accordingly planned in such a way that each of the factors that theoretically might influence the load-stress relation could be examined experimentally and the observed effects compared with those predicted by the theory. In addition, this study was expected to indicate rather definitely what the shape of the slab cross section should be if the design were so balanced that a given load would produce a certain definite maximum stress regardless of the position of the load on the slab.

The study of the balance of design of typical pavement slab cross sections was planned, first, for the purpose of showing the relative economy of the various designs, and second, to provide data upon which to base conclusions as to the proper shape for a perfectly balanced cross section. The data obtained in the load tests on slabs of uniform thickness mentioned in the last part of the preceding paragraph necessarily form an important part of the study of the balance of the cross-section design.

The almost complete lack of data concerning the structural behavior of the various types of longitudinal and transverse joint designs existing at the time this research was planned and the importance of a knowledge of this action in any consideration of the structural design of pavements made a study of the subject imperative. That part of the investigation dealing with joint design was planned to yield data showing the structural effectiveness of most of the commonly used types of joints and also information regarding the effect of dowel spacing and joint width on the structural action of joints.

The fourth part of the investigation, that is, the study of the effects of temperature conditions and of moisture conditions on the size, shape, and load-carrying ability of pavement slabs, was planned to provide information, not heretofore available, on the complex relations created by temperature and moisture variations, and the practical significance of these relations with respect to the design of the pavement slab as a load-carrying structure.

In order to carry out the studies contemplated in this investigation the group of 10 full-size concrete pavement slabs shown on the cover page was constructed. Each of these slabs is 40 feet in length, 20 feet in width, and has a particular cross section. Each slab is divided by a longitudinal and a transverse joint of a particular design and each slab is definitely separated from those adjoining it, in most cases by a 2-inch open joint. The concrete was uniform throughout the group and all slabs were without steel reinforcing. Special efforts were made to obtain subgrade uniformity under the entire group of sections.

The load tests and other studies designed to develop the information desired have been made on these 10 slabs. Some idea of the magnitude of the work of testing may be had when it is realized that, in round numbers, some 30,000 strain measurements, 25,000 deflection observations, 65,000 measurements of slab expansion (or contraction), and 30,000 temperature measurements were made in the course of the investigation. Approximately 10 percent of these were made during the night or early morning hours.

Figure 1 shows the details of the several designs of pavement slab cross section included in the investigation. It will be observed that these include the rather massive edge design suggested a number of years ago by the American Association of State Highway Officials, 3 designs of the conventional thickened-edge type in which the edge thickening is decreased uniformly to zero over a distance of 3 feet, a design in which the upper and lower boundaries of the section are parabolas diverging so as to give a thickened edge, 2 lip-curb sections (with and without the conventional edge thickening), and 4 sections of uniform thickness. The area of the cross section (in square feet) for a 20-foot width pavement of each design is noted in this figure.

The details of the several designs of transverse joint included are shown in figure 2. The ordinary butt-type open joint with 3 different dowel spacings and 2 different widths of joint opening, the continuous steel plate key with 2 widths of joint opening, the thickened slab end (without dowels or other connection), and the "plane of weakness" both with and without dowels

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[1] Roscoe Lancaster, Harry D. Cashell, Arthur L. Catudal, and Ernest G. Wiles, junior highway engineers, gave able assistance in carrying on the work reported. They contributed valuable suggestions as to procedure and made observations at all hours and under all weather conditions.

[2] A series of five articles has been planned. The first three will probably be published in consecutive issues. Parts 4 and 5 may not be published in issues consecutive with the rest of the series as they are dependent upon work yet to be completed.

[3] Stresses in Concrete Pavements Computed by Theoretical Analysis, by H. M. Westergaard, PUBLIC ROADS, vol. 7, no. 2, April 1926, and Analytical Tools for Judging Results of Structural Tests of Concrete Pavements, by H. M. Westergaard, PUBLIC ROADS, vol. 14, no. 10, December 1933.

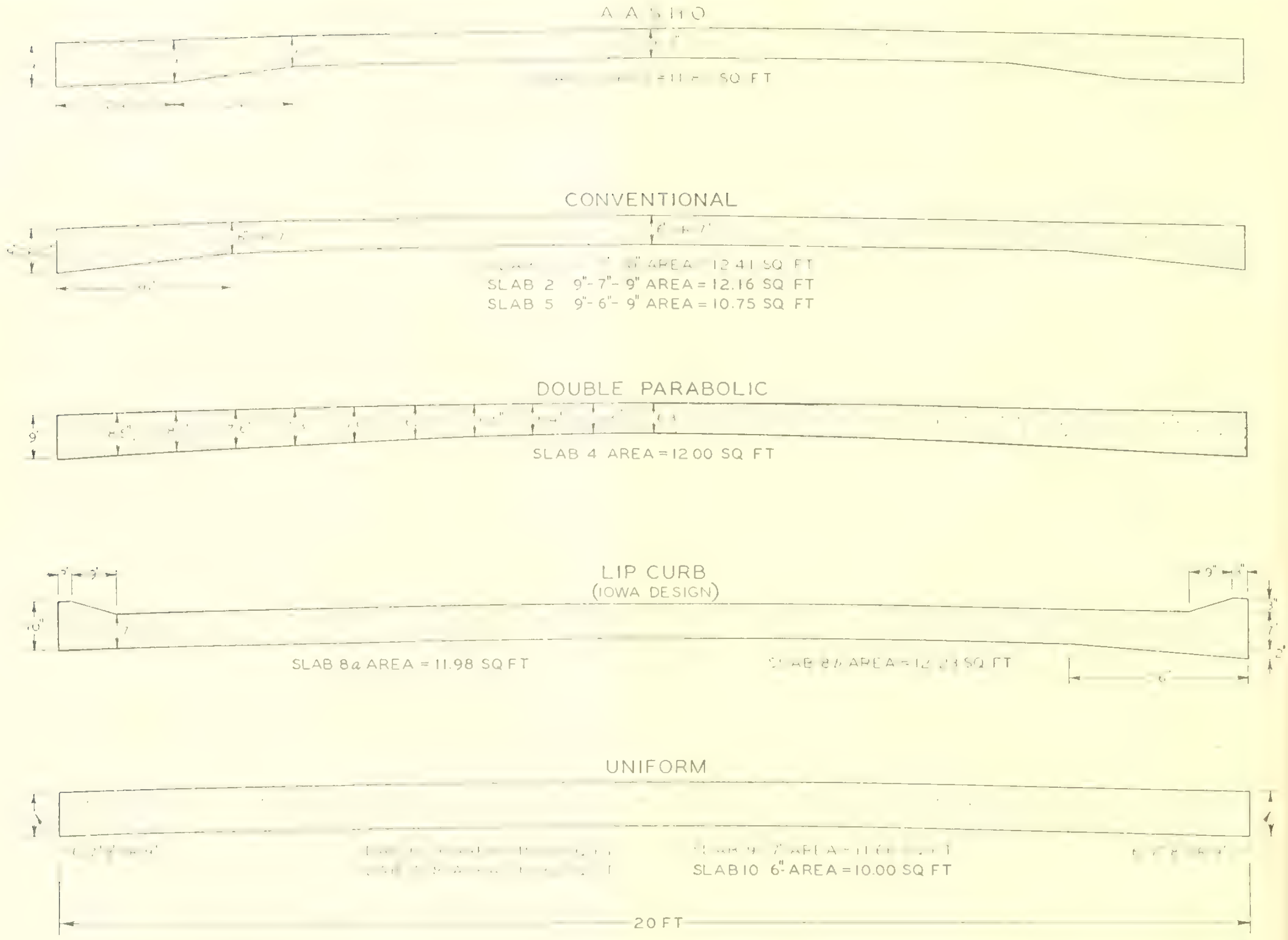

AASHO
SQ FT
CONVENTIONAL
AREA 12.41 SQ FT
SLAB 2 9"-7"-9" AREA = 12.16 SQ FT
SLAB 5 9"-6"-9" AREA = 10.75 SQ FT
DOUBLE PARABOLIC
9"
SLAB 4 AREA = 12.00 SQ FT
LIP CURB
(IOWA DESIGN)
SLAB 8a AREA = 11.98 SQ FT
UNIFORM
SLAB 10 6" AREA = 10.00 SQ FT
20 FT

Figure 1.—Designs of Cross Sections Investigated.

comprise the types that have been tested. All of the joints have been kept filled with a typical poured bituminous joint filler.

The structural features of the several types of longitudinal joints used in the 10 slabs are shown in figure 3. In 4 of these, separation of the 2 slabs was accomplished with a deformed plate of heavy sheet metal; in 4 others the slabs were laid half width at a time and bond between the halves of the slab was prevented by a sheet of tarred felt. The other 2 slabs were grooved to create a longitudinal plane of weakness that was intended to crack through and form a separation between the 2 halves of the slab.

TEST SLABS CAREFULLY CONSTRUCTED

The subgrade.—The importance of subgrade uniformity in any test of the structural action of pavement slabs was recognized from the first. The site used was selected with this in mind and a detailed soil survey was made to determine the conditions existing in the area involved, with the result that the soil was classified as a uniform brown silt loam (class A–4). The uniformity of the soil is indicated by the results of tests made in the laboratory on the samples taken during the survey, as shown in table 1.

The original surface of the area having been disturbed by earlier experiments, the subgrade material was entirely removed until the new subgrade was entirely an undisturbed soil formation. On this surface the lin of the pavement was laid out. In order to insur proper drainage, deep side ditches with suitable outlet were provided.

Table 1.—*Test data from subgrade samples*

Sample no.	Liquid limit	Plasticity index	Shrinkage		Moisture equivalent	
			Limit	Ratio	Centrifuge	Field
1	24	8	18	1.8	28	20
2	22	5	21	1.7	23	19
3	25	8	19	1.8	26	21
4	24	9	19	1.8	25	2
5	25	9	19	1.8	26	1
6	24	6	18	1.8	28	1
7	23	8	19	1.8	20	1
8	25	9	17	1.8	25	2
9	23	7	18	1.8	19	2
10	32	12	24	1.6	35	2
11	24	7	20	1.8	26	2
12	28	9	24	1.7	34	2
13	24	9	20	1.8	24	2
14	27	12	16	1.8	23	2
15	25	10	17	1.8	25	1
16	25	10	17	1.8	25	1
17	24	8	19	1.8	23	1
18	25	9	18	1.8	24	2
19	24	9	18	1.8	25	2
20	24	7	20	1.8	27	2
21	23	8	18	1.8	23	2
22	24	8	18	1.8	27	1
23	30	14	19	1.8	22	2
24	28	13	18	1.8	27	2
25	29	11	16	1.8	31	2

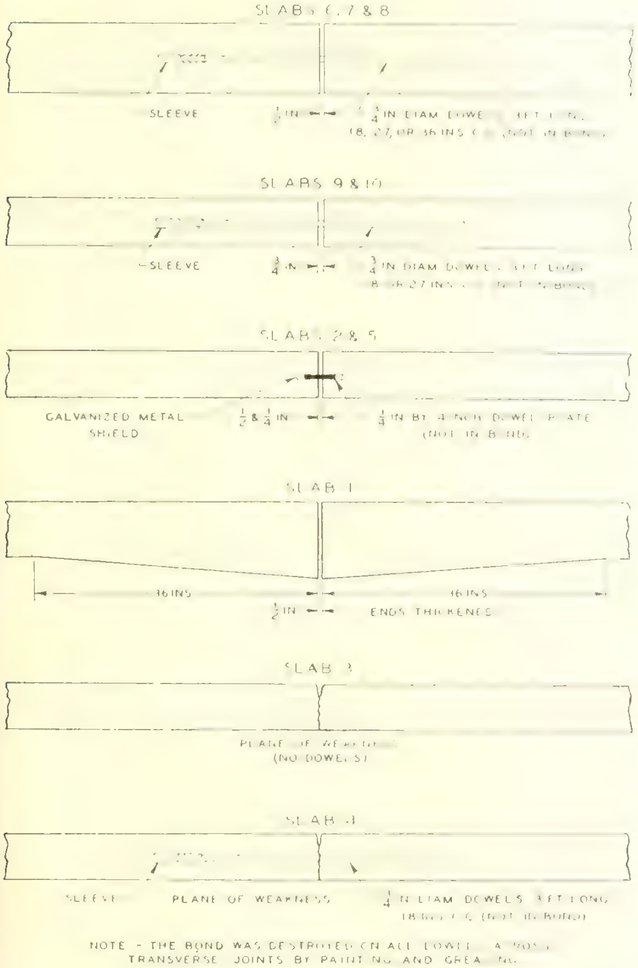

SLABS 6, 7 & 8
SLEEVE
IN
¾ IN DIAM DOWELS 3 FT LONG, 18, 27, OR 36 INS C. C. (NOT IN BOND)
SLABS 9 & 10
SLEEVE
¾ IN
¾ IN DIAM DOWELS 3 FT LONG 18 OR 27 INS C. C. (NOT IN BOND)
SLABS 2 & 5
GALVANIZED METAL SHIELD
½ & ¾ IN
¼ IN BY 4 INCH DOWEL PLATE (NOT IN BOND)
SLAB 1
36 INS
36 INS
½ IN
ENDS THICKENED
SLAB 3
PLANE OF WEAKNESS (NO DOWELS)
SLAB 4
SLEEVE
PLANE OF WEAKNESS
¾ IN DIAM DOWELS 3 FT LONG 18 INS C. C. (NOT IN BOND)
NOTE - THE BOND WAS DESTROYED ON ALL DOWELS ACROSS TRANSVERSE JOINTS BY PAINTING AND GREASING.

FIGURE 2.—DESIGNS OF TRANSVERSE JOINTS INCLUDED IN THE INVESTIGATION.

The subgrade where the slabs were to be located was next plowed to a depth of approximately 10 inches. It was left in this loose condition for a period of about 4 weeks, during which it was broken up and agitated several times with a disk harrow. The soil was finally compacted, first with a 5-ton tandem roller and then with the wheels of a loaded 5-ton motor truck. The appearance of the subgrade after this manipulation is shown in figure 4. On this compacted soil the forms were set and the final grading completed. Because of the purpose for which the slabs were to be used, great care was taken to have the final subgrade surface exactly to grade and very smooth in order that the thickness of the completed slab would be known definitely. The appearance of the subgrade at the time the concrete was placed is shown in figure 5.

The moisture content of the subgrade was maintained by sprinkling daily and the particular portion on which concrete was to be placed was given an additional light sprinkling immediately prior to placing concrete.

The concrete.—The materials used for the concrete were carefully selected and the mix designed to give high flexural strength. The cement was a standard portland cement of satisfactory quality, and all came from one bin at the plant.

The fine aggregate was a rather coarse, angular quartz sand, containing some grains of chert, feldspar, gneiss and mica. The average fineness modulus of the sand as determined by a number of tests was 3.26. The source of this material is near Fredericksburg, Va.

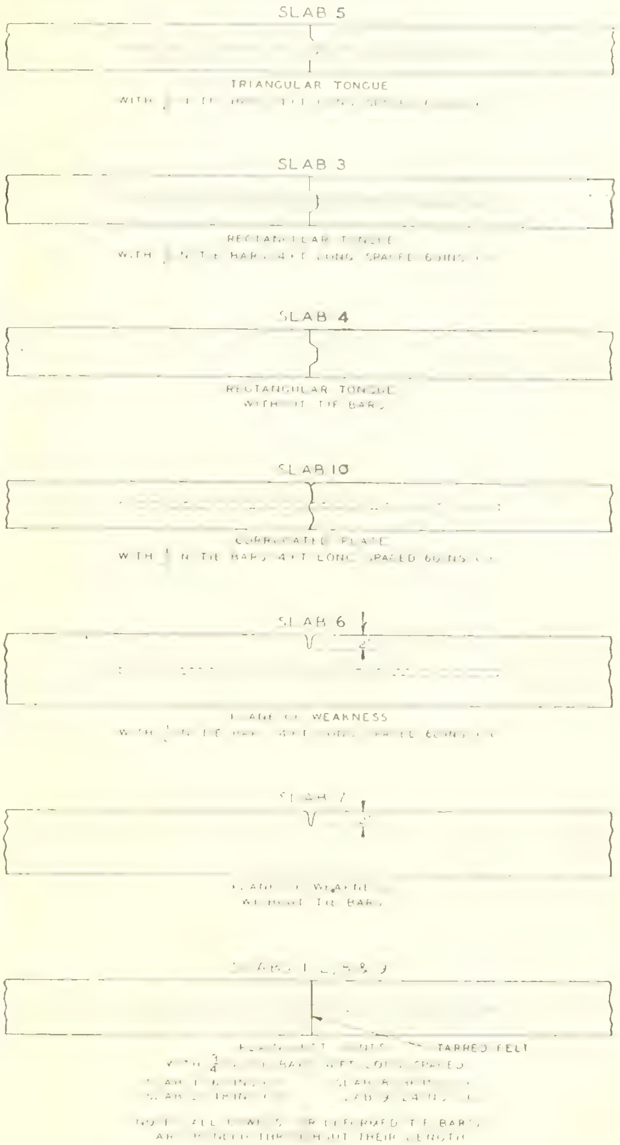

SLAB 5
TRIANGULAR TONGUE
WITH ½ IN TIE BARS 4 FT LONG, SPACED
SLAB 3
RECTANGULAR TONGUE
WITH ½ IN TIE BARS 4 FT LONG SPACED 60 INS C. C.
SLAB 4
RECTANGULAR TONGUE WITHOUT TIE BARS
SLAB 10
CORRUGATED PLATE
WITH ½ IN TIE BARS 4 FT LONG SPACED 60 INS C. C.
SLAB 6
2"
PLANE OF WEAKNESS
WITH ½ IN TIE BARS 4 FT LONG SPACED 60 INS C. C.
SLAB 7
2"
PLANE OF WEAKNESS WITHOUT TIE BARS
SLABS 1, 2, 8 & 9
PLAIN BUTT JOINTS
TARRED FELT
WITH ¾ IN TIE BARS 4 FT LONG SPACED
NOTE - ALL DOWELS OR DEFORMED TIE BARS ARE BONDED THROUGHOUT THEIR LENGTH

FIGURE 3.—DESIGNS OF LONGITUDINAL JOINTS INCLUDED IN THE INVESTIGATION.

The coarse aggregate was a blue limestone obtained from near Martinsburg, W. Va. It was shipped to the job in three sizes and recombined at the proportioning plant to give the desired grading. The proportions used were:

Size:	*Percent*
1¼ to 2¼ inches	50
¾ to 1¼ inches	25
¼ to ¾ inch	25

When combined in this way the average fineness modulus of the coarse aggregate was 7.65.

The proportions fixed for the concrete were 1: 2: 3½, using dry-rodded volume as the basis of measurement. Actually, in batching materials for the mixer, these proportions were controlled by weighing all of the constituents except the water. Figure 6 shows the

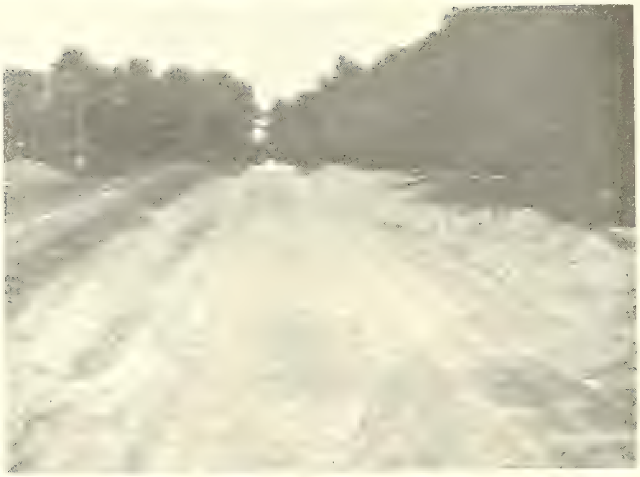


FIGURE 4.—APPEARANCE OF THE SUBGRADE AFTER ROLLING HAD BEEN COMPLETED.

proportioning plant used in the construction of the slabs.

Moisture determinations were made on samples from the stock piles each morning and necessary adjustments were made in the batch weights and water content. The water-cement ratio decided upon as a result of trial mixes was 0.85 by volume.

Concrete was mixed for 1½ minutes in a modern paving mixer (size 27–E). At the beginning of each day's run, a preliminary half-size batch was run through the mixer and discarded, the purpose being to coat the interior of the mixer drum and obtain uniformity in subsequent batches. The concrete was dumped on the subgrade and distributed in the usual manner. Compacting and finishing were accomplished with a 2-screed finishing machine, without tamping. The final finish was obtained with a hand belt and edging tools. A double layer of wet burlap was applied immediately after the final belting and this was kept wet for 24 hours, after which it was replaced with a layer of earth 3 to 4 inches thick, which was kept wet for 20 days and then removed. Figure 7 shows the equipment used in mixing and placing the concrete.

In order to have concrete available for such later studies of the physical properties of the concrete as might be necessary, three short extra sections of pavement were cast during the construction of the test slabs.

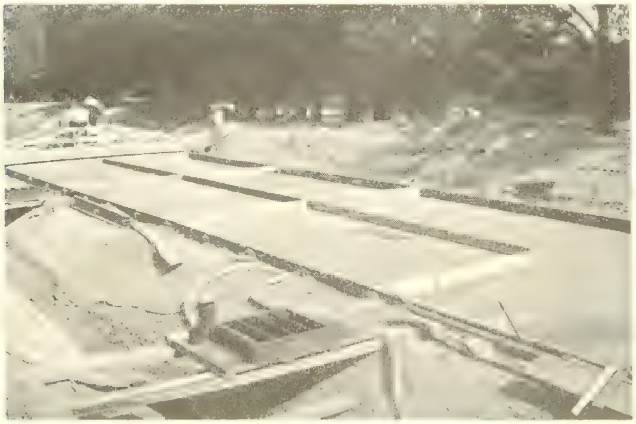


FIGURE 5.—APPEARANCE OF THE SUBGRADE AFTER FORM SETTING AND COMPLETION OF THE FINAL GRADING.

For an early determination of concrete strength, 8 beams and 5 cylinders were made for each of the 10 pavement slabs. These specimens were cast from the concrete after it had been dumped on the subgrade. The beams were 7 by 7 by 30 inches and the cylinders 6 by 12 inches in size. These specimens were protected from moisture loss during the first 24 hours, after which the cylinders were removed to the damp room and the beams were buried in the earth shoulder beside the slab. All of these specimens were tested at the age of 28 days.

The average flexural strength of the beams (80 specimens) was 765 pounds per square inch and the average compressive strength of the cylinders (46 specimens) was 3,525 pounds per square inch.

TEST PROCEDURE DESCRIBED

The tests and observations made in this investigation may be divided into three groups, as follows:

1. Load tests on the pavement slabs, in which definite loadings were applied to the various sections according to a plan and the resulting deflections and strains were measured. These tests form the basis of—

(*a*) The examination of the Westergaard analysis.

(*b*) The study of the pavement cross-sections.

(*c*) The determination of the structural efficiency of the different joint designs.

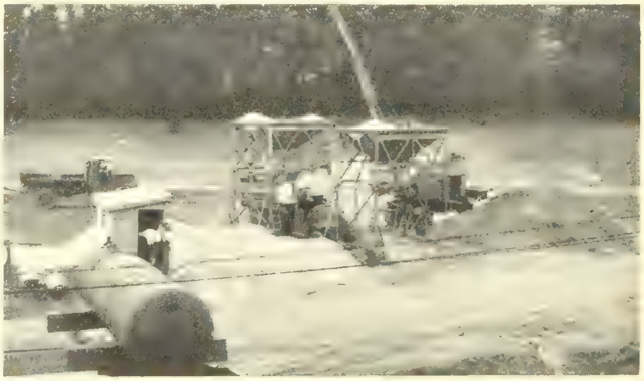


FIGURE 6.—THE PROPORTIONING PLANT.

2. Observations made on the slabs to determine th effects of variations in temperature and moisture conditions on their size, shape, and load-carrying ability These observations included the determination of—

(*a*) Temperature conditions within and surrounding the pavement.

(*b*) The expansion, contraction, and warping o slabs due to temperature changes and to changes i moisture condition.

(*c*) The strains induced in the concrete through th tendency of the slab to change its size and shape.

3. *Auxiliary tests.*—This group comprises a considerable number of collateral investigations carrie out principally in the laboratory, to develop information essential to the interpretation of the data obtaine in the tests on the slabs. In this group will be foun tests to determine—

(*a*) The physical characteristics of the subgrade.

(*b*) The physical properties of the concrete.

(*c*) The thermal properties of the concrete.

(*d*) The effect of moisture conditions on the strengt and stiffness of the concrete.

PROGRAM OF LOAD TESTS BASED ON CAREFUL PRELIMINARY INVESTIGATIONS

Before beginning the general program of load tests, preliminary tests were made on a slab of uniform thickness and on one having a conventional thickened edge. The purpose of these preliminary tests was to determine—

1. The proper points at which to apply the loads for the various studies.
2. The proper position for the strain gages if the critical strain was to be measured for each loading.
3. The extent of the deflections to be measured for each loading.

The information obtained in these tests made possible the detailed planning of the tests that were to follow.

An important development of this preliminary work was the conclusion that relative deflections, as measured in these tests, may not always be a true indication of relative stresses. Since deflection and stress are directly related theoretically, it seems probable that the deflection data, while apparently accurate, are actually quite crude when compared to the strain data. Thus, differences in elastic curvature that are not detectable in the deflection data may cause large differences in stress.

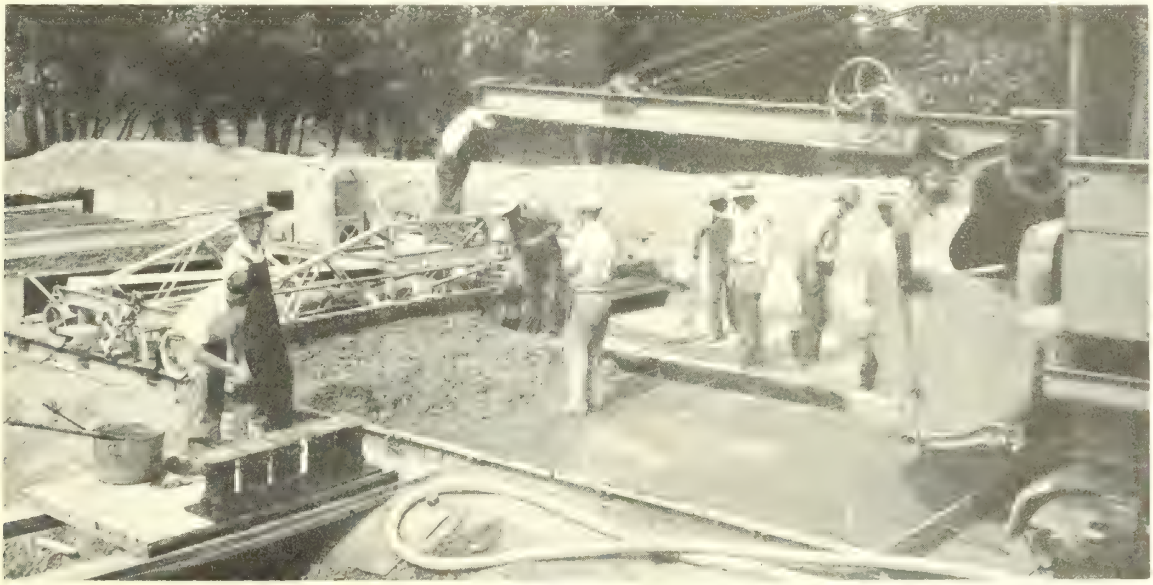


FIGURE 7.—THE MIXING AND PLACING OF THE CONCRETE.

This conclusion made it necessary to depend almost entirely upon the stress data as a basis for the comparisons that it was desired to make.

As soon as the preliminary tests had been completed detailed plans for the load-testing program were developed. Figure 8 shows the plan and elevation of one of the test sections and the points where loads were applied for the different studies and the positions of the strain gages in relation to the load points. Figure 9 is a similar drawing showing the points where loads were applied and the lines along which the deflection curves were determined. This figure also shows the location of the points where the opening and closing of the joints due to temperature were measured.

In the studies of the balance of the designs of slab cross-section the load was applied successively at points 1 foot apart along the transverse axis of one of the quarter-slab panels (points 1 to 10, inclusive, along the line A′—B′ in fig. 8).

For the investigations of joint design, loads were applied at the joint edge, at the center of the slab panel, and at the free edge of each slab, thus permitting a comparison to be made between the maximum stresses developed by a given load acting at the joint edge and those developed by the same load at the other two points, points that represent the extreme limits of slab continuity. These stress data make it possible to set up a rational measure of the structural effectiveness of joint designs.

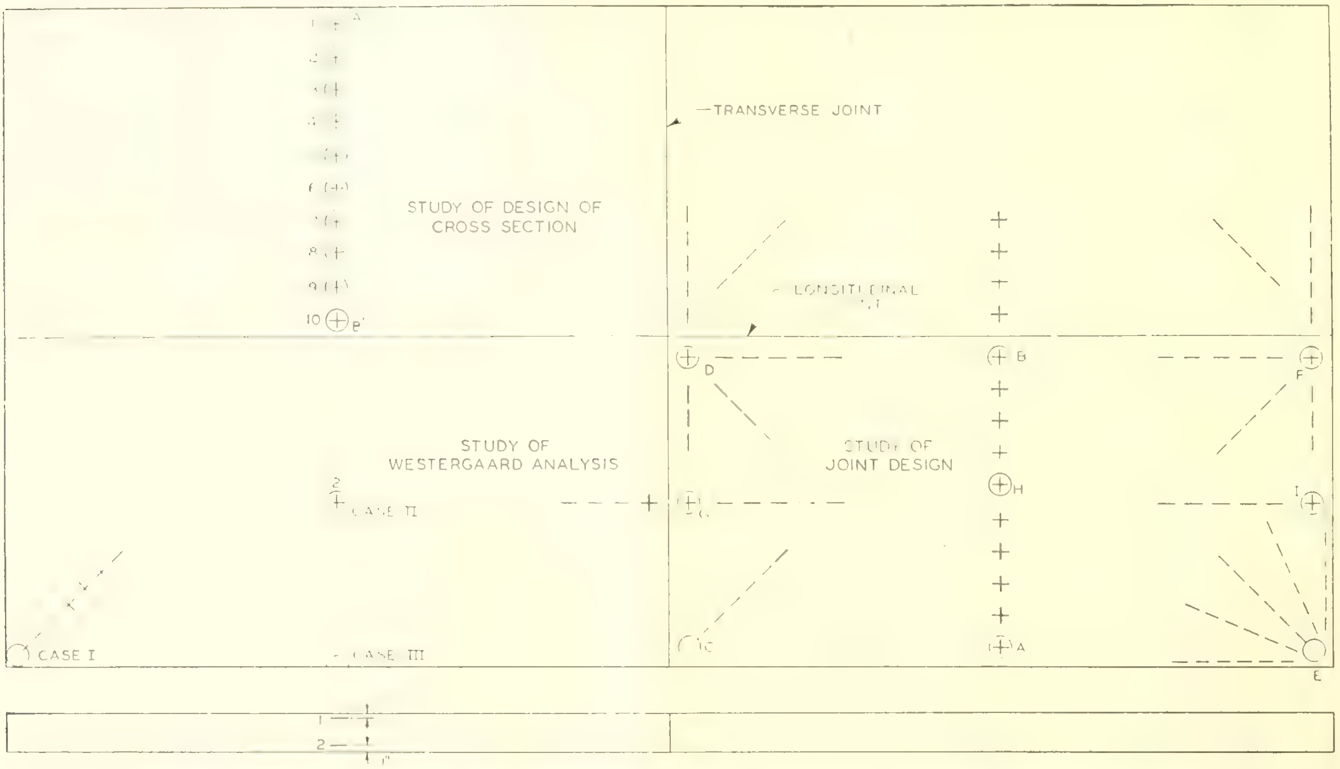
In the case of the longitudinal joints the load points A, H, and B were used, while for transverse joints the loads were applied at I, H, and G. As the program advanced it was found that some joint designs were not equally effective at all points nor at all times of the year, so that additional loads were applied along lines parallel to the slab axes but displaced from the center line. In all cases, however, the complete data were obtained for the three positions of the load.

When Westergaard prepared his analysis of the stresses in a concrete pavement slab, he developed a mathematical treatment covering three important cases of loading that were: Case I, a wheel load acting at the free corner of a slab; case II, a wheel load acting at the interior of a slab and at a considerable distance from the edges; case III, a wheel load acting at the edge of a slab and at a considerable distance from a corner.

The loadings applied to the test slabs in the study of the three cases of the Westergaard analysis are shown in figure 8. These tests were made only on the slabs of uniform thickness. For every loading the significant stress and deflection data were obtained. Figure 10 shows the appearance of one of the test sections after the installation of the gage points for the strain and deflection measurements.

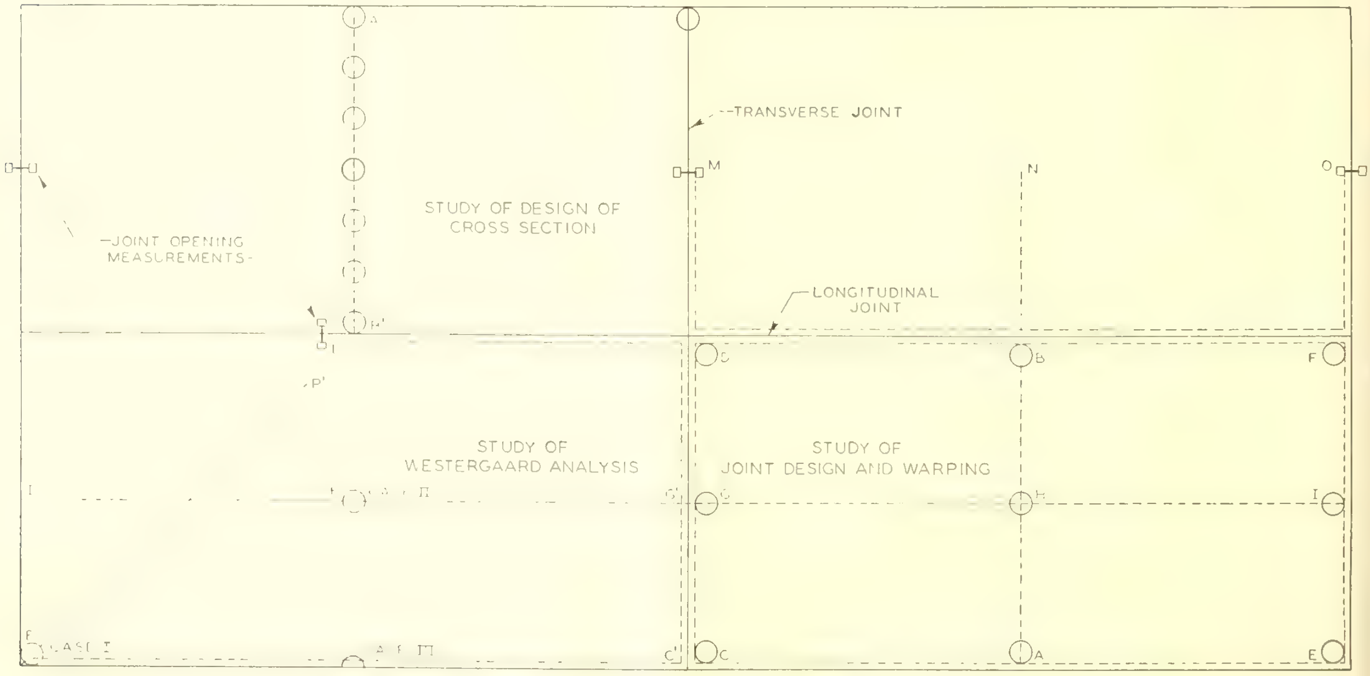
METHOD OF APPLYING LOADS DESCRIBED

It was considered desirable to use loads that would create maximum stresses of approximately one-half of the modulus of rupture of the concrete. Since some of the slabs were of rather heavy design, reactions of some



LEGEND – CIRCLES SHOW POINTS AT WHICH LOADS WERE APPLIED SHORT LINES SHOW LOCATION OF STRAIN GAGES

FIGURE 8.—PLAN AND ELEVATION OF A 20- BY 40-FOOT TEST SECTION, SHOWING THE POINTS WHERE LOADS WERE APPLIED AND THE LOCATIONS OF THE STRAIN GAGES.


A
TRANSVERSE JOINT
M
N
O
JOINT OPENING MEASUREMENTS
STUDY OF DESIGN OF CROSS SECTION
LONGITUDINAL JOINT
B'
P'
D
B
F
STUDY OF WESTERGAARD ANALYSIS
STUDY OF JOINT DESIGN AND WARPING
CASE II
G
H
I
CASE I
CASE III
C
A
E

▣ REFERENCE POINT (FIXED ELEVATION)

LEGEND – CIRCLES SHOW POINTS AT WHICH LOADS WERE APPLIED, DASH LINES SHOW LOCATION OF CLINOMETER POINTS.

FIGURE 9.—PLAN OF A 20- BY 40-FOOT TEST SECTION SHOWING THE POINTS WHERE LOADS WERE APPLIED AND THE LINES ALONG WHICH DEFLECTIONS WERE MEASURED.

magnitude were necessary to produce such stresses. It was also highly desirable that at the time the test load was being applied no other loads be on the slab, in order that the observed effects could be attributed definitely to a known reaction system. These two considerations and the availability of a large cylindrical steel tank led to the adoption of the loading equipment shown in figure 11. The tank, 30 feet long and 6 feet in diameter, was mounted in a structural steel frame or cradle, supported by two transverse end frames 22 feet apart. Each end frame was provided with a pair of heavy cast-iron wheels of small diameter and these rested upon a railway laid along the earth shoulders parallel to the pavement edge. The tank spanned the slab completely and could be moved longitudinally over the test sections at will.

A heavy wooden bolster or pad was fitted to the lower surface of the tank and so arranged that it could be shifted to any position from one end frame to the other, and thus be placed over any desired point on any of the sections.

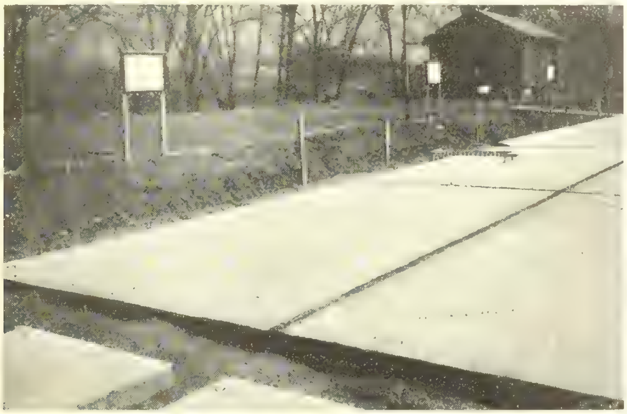


Figure 10.—Complete Installation of Gage Points for Strain and Deflection Measurements on One of the Test Sections.

By partially filling the tank with water a reaction in excess of any load required for the loading of the slabs became available. To develop the load on the slab the device shown in figure 12 was constructed. In this figure, A is the wooden bolster that bears against the bottom of the tank, B is a steel facing plate on the lower surface of the bolster, C is a hardened steel knife edge, D is a pair of heat-treated steel beams whose load-deflection rate being known through calibration enables the operator to determine the load on them at any instant by reading the micrometer dial that measures their deflection, E is a ball-bearing screw jack used for developing the thrust, F is a spherical bearing block that prevents eccentricity of loading on the bearing plate G, and H is a sponge-rubber pad to take up surface irregularities on the slab and assure a uniform intensity of load over the entire area of the bearing block.

The capacity of the loading device shown in this figure is approximately 25,000 pounds. One division on the micrometer dial is equivalent to a load increment of about 30 pounds and periodic calibrations have led to the conclusion that the load measurement by this means can be depended upon to be accurate within 100 pounds, which makes the percentage of error small for loads of the magnitudes used in these tests.

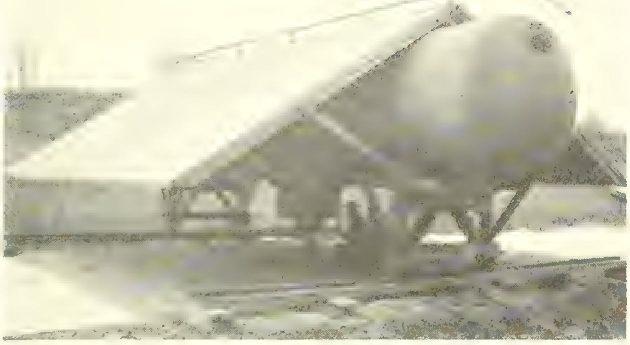


Figure 11.—Loading Equipment in Place Over One of the Test Sections. The Slab is Covered with Straw and Shaded to Prevent Warping.

The bearing blocks that received the thrust of the jack and applied it to the pavement were of two types and of several sizes. For the study of the Westergaard theory it was necessary to use blocks having both circular (fig. 13 A) and semicircular bearing areas (fig. 13 B), circular for the interior and corner loadings and semicircular for the edge, in order to meet the assumptions of the analysis. Also it was necessary to use several sizes of each in order to investigate the effect of the size of the bearing area on the maximum stress caused by a given load. The diameters of the blocks selected were 6, 8, 12, 16, and 20 inches. The majority of the tests were made with the 8-inch diameter circular block. For the corner loadings the full circular plates were used. When the larger plates were used, distribution of the load was obtained by pyramiding the plates as shown at the right hand side of figure 13 A and also in figure 12.

In a number of the tests, such as those at the interior of the pavement slab, it was necessary to measure the strain in the concrete directly under the bearing plate. For these tests special blocks, provided with a groove across the bottom face large enough to accommodate a

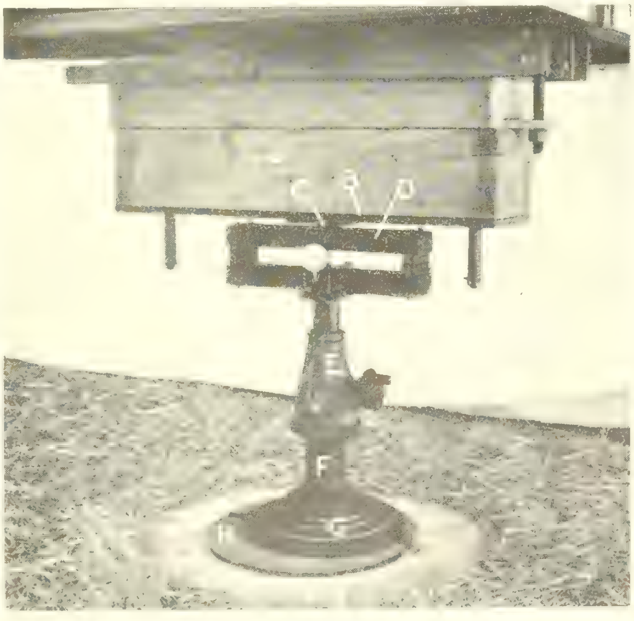


Figure 12.—Apparatus for Applying the Load and for Measuring Its Magnitude.

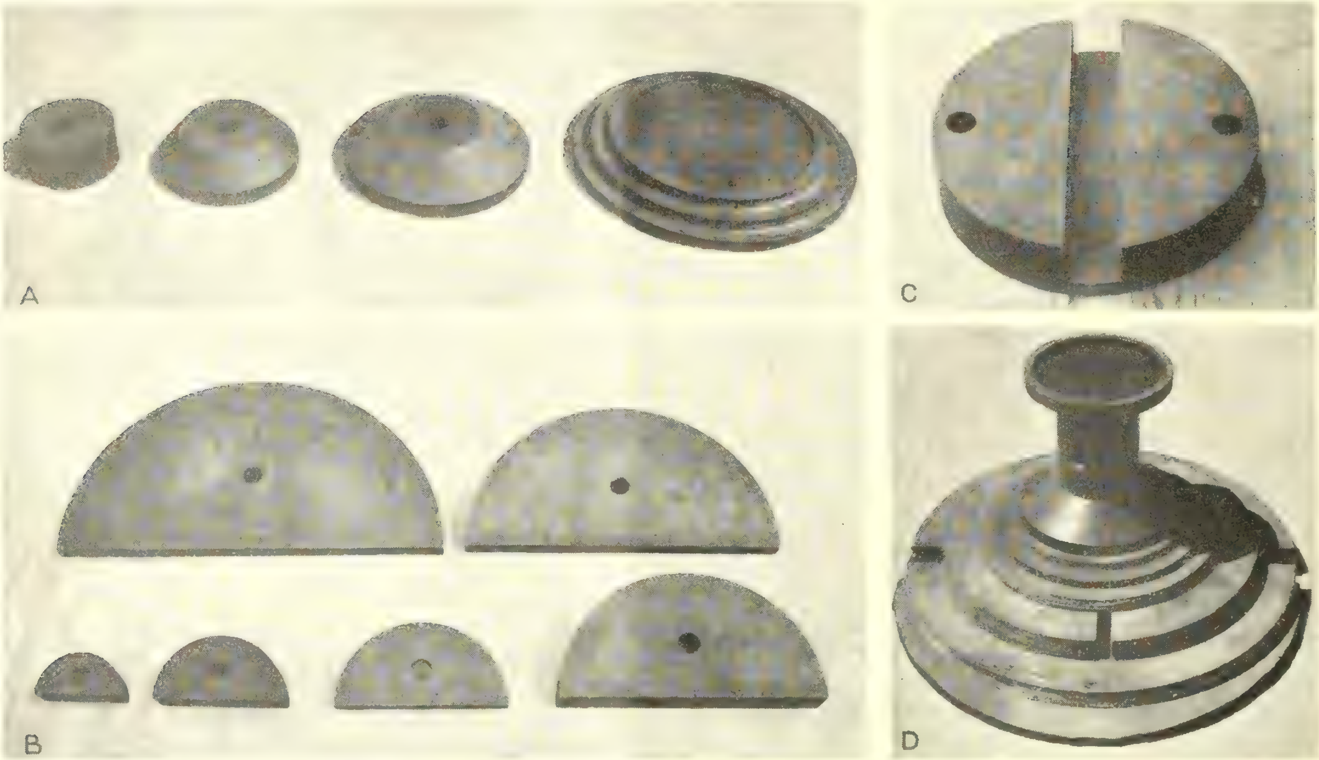


Figure 13.—Bearing Plates: A, Circular Bearing Plates Used in the Corner Loading Tests; B, Semicircular Plates Used for the Edge Loading Tests; C, Small Circular Bearing Block Grooved to Provide Space for a Strain Gage. The Block Is Shown Inverted. D, Large Circular Bearing Block With Space for a Strain Gage in the Lower Plate.

strain gage, were used. The smaller blocks of this type were built as shown in figure 13 C. For the larger areas two segments of the proper size were placed on the sponge-rubber pads on either side of the strain gage and the load was distributed to these by superimposed circular plates as shown in figure 13 D.

Both circular and semicircular plates were used as bearing blocks for the tests at the edge of the pavement slab. The circular plates were the same ones used in the corner loading tests and the semicircular plates were those shown in figure 13 B.

All of the bearing blocks were made of steel and were so designed that the deflection under load produced a negligible effect on the uniformity of load distribution. The effect of the groove in the bearing block on the maximum stress in the slab was investigated and the tests showed that for a given load the grooved block caused the same maximum strain as a block of the same diameter without the groove.

A study was made of the effect of load duration on the magnitude of the strain developed in the concrete. It was found that in some positions, on some of the pavement designs, essentially the maximum strain was developed after the load had been maintained for 1 or 2 minutes, while at other points, 4 or 5 minutes was necessary before this equilibrium was established. As a result of this study the procedure of maintaining the load for 5 minutes before making any strain measurement was adopted for all of the tests. Conversely, 5 minutes was allowed for recovery after the release of each load before the application of the next load. The strains reported in the papers that are to follow are, therefore, maximum strains for the particular loads and are all definitely larger than would be caused by momentary loads of the same magnitude.

ACCURATE MEASUREMENTS OF STRAIN OBTAINED WITH SPECIAL GAGES

Throughout the investigation the strains in the concrete were measured with the recording strain gage shown in figure 14. The gage and its characteristics have been described in detail elsewhere [4] and will be dealt with only briefly here. It consists of a body or frame about 6 inches in length carrying a simple bell crank lever with arms of unequal length. The short arm of this lever is moved by any displacement of the gage points between which the gage is mounted. This motion is transmitted to the long arm of the lever and of course magnified by the ratio of the lengths of the two arms. The long arm of the bell crank carries a stylus point at its free end which makes a trace on the smoked surface of a small glass plate, thus recording a displacement of the end of the arm. The trace on the record slide is thus proportional to the displacement of the gage points and its length is measured, either directly with a comparator or by optical magnification in a projection apparatus. The mechanical magnification in the gage is about 60:1 and ordinarily another magnification of about 30:1 is had in the projection apparatus.

The gages were designed to eliminate ordinary temperature effects. The gage body from tip to tip is made of the alloy "invar", and further compensation is obtained through the use of a pair of dissimilar metals in the long (or stylus) arm of the bell-crank lever.

The accuracy of the gages is sufficient to permit the determination of stress in concrete to within 20 or 25 pounds per square inch, where dependence is placed upon a single observation.

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[4] An Improved Recording Strain Gage, by L. W. Teller, Public Roads, vol. 14, no. 10, December 1933.

The strain gage is approximately 6 inches in length. Early in the consideration of the program the question was raised as to whether or not a gage of this length would record maximum strains when used under bearing blocks of the sizes that it was desired to use. This matter was investigated rather thoroughly by using special gages of various lengths placed under bearing blocks of a range of sizes, and the data obtained indicated quite conclusively that the gages would record the maximum strain, provided that the entire gage and gage points were within the circumference of the bearing plate and that the axis of the gage lay along one of the diameters of the plate. Theoretically, the stress is not exactly uniform across the area of the slab under the bearing plate, and it is probable that, had it been possible to measure strains with greater precision, the variation due to length of gage would have been detected. With the apparatus described, however, the same maximum unit strain was indicated by at least 3 different lengths of gage under bearing plates of several sizes, so long as the gages were placed in accordance with the 2 provisions mentioned above. As a result of these tests, it was concluded that the 6-inch gage would record approximately the maximum strain if used with bearing plates with a diameter of 6 inches or more.

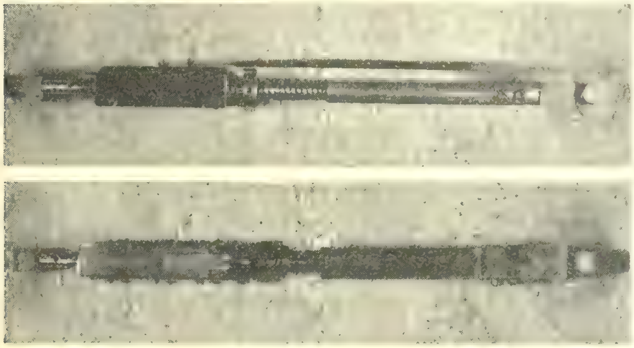

FIGURE 14.—RECORDING STRAIN GAGE OF THE TYPE USED IN THIS INVESTIGATION MOUNTED BETWEEN TWO GAGE POINTS.

In use the gages were installed between two small brass posts containing drilled and reamed gage holes. These posts, ¼ by ¼ by 1½ inches in size, were set into small holes drilled in the surface of the concrete to a depth of about 1 inch immediately before each test, being held in place with plaster of paris. Various other cementing materials were tried, but it was found that with time the posts tended to work loose with all of them and that, for a temporary setting, plaster of paris was as satisfactory as any of them and considerably more convenient to use.

As usually installed the axis of the strain gage was one-fourth of an inch from the surface of the concrete. This caused the recorded strain to be greater than the strain at the surface of the pavement by an amount that depended upon the relative distances of the gage and that surface from the neutral plane of the pavement slab. In most of the measurements, it was therefore necessary to apply a small correction to the observed strains in order to compensate for the gage position. Figure 15 shows an installation of the gages for a load test at the corner of a slab of constant thickness.

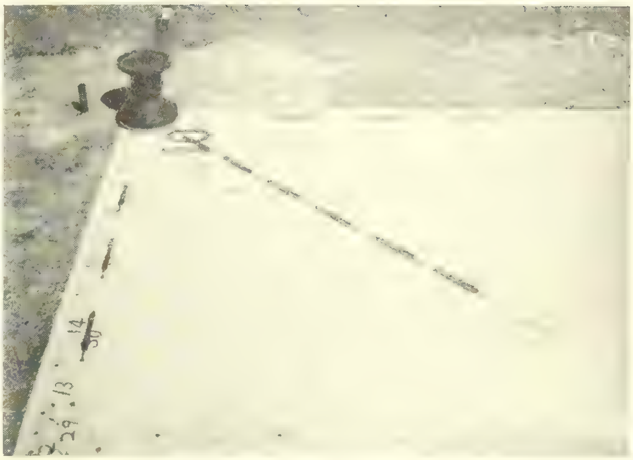

FIGURE 15.—ARRANGEMENT OF STRAIN GAGES FOR A LOAD TEST AT THE CORNER OF A SLAB OF UNIFORM THICKNESS.

DEFLECTIONS MEASURED WITH CLINOMETERS

The deflection measurements in this investigation were made with the clinometer or "level-bar" shown in figure 16. This instrument was built especially for the project from a design developed by the Bureau in connection with a recent highway bridge research,[5] the principle of the instrument being the same as that of the clinometer loaned by the American Society of Civil Engineers for the tests of the Yadkin River Bridge.[6]

It consists of a rigid, horizontal steel frame carrying a very sensitive spirit level in its upper face and supported by a vertical leg at each end. One of these legs is of fixed length while the length of the other is adjustable by means of a fine pitch screw operated by a knurled hand nut at the top of the instrument. The amount of adjustment made with this nut is indicated in thousandths of an inch by a micrometer dial on the front of the frame. In order that the position assumed by the instrument when it is placed on the clinometer points shall always be the same, a third or steadying leg is provided, projecting at right angles from the center of the frame and turning down at the outer end where it terminates in an adjustable foot.

Small brass cylinders were grouted into holes drilled in the pavement surface at 10-inch intervals along the lines of desired deflection measurements. The upper or exposed face of each of these contained a small verti-

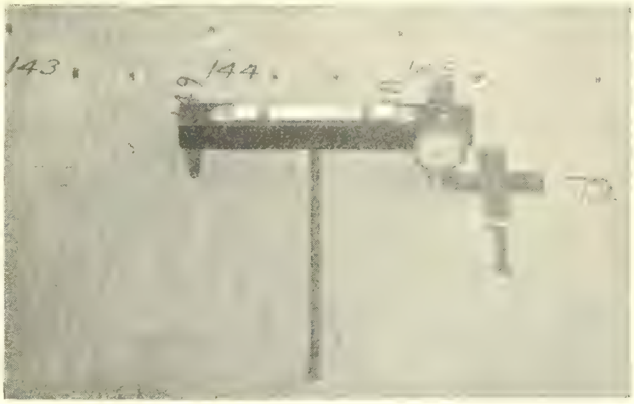

FIGURE 16.—SPECIAL 10-INCH CLINOMETER USED FOR MEASURING SLAB DEFLECTIONS. THE INSTRUMENT IS SHOWN RESTING ON SMALL BRASS CLINOMETER POINTS SET INTO THE SURFACE OF THE PAVEMENT.

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[5] Application of the Freyssinet Method of Arch Construction to the Rogue River Bridge in Oregon, by Albin L. Gemeny and Conde B. McCullough. Technical Bulletin No. 2 of the Oregon State Highway Commission, Salem, Oreg.

[6] Loading Tests on a Reinforced Concrete Arch, reported by Albin L. Gemeny and W. F. Hunter, PUBLIC ROADS, vol. 9, no. 10, December 1928.

cally drilled hole and also a narrow horizontal groove or slot with beveled edges. The direction of the slot was made parallel to the long axis of the clinometer frame when the instrument rested on the points. The lower ends of the 2 main clinometer legs are sharp-pointed cones and in setting up the instrument 1 of the legs is set in the drilled hole in the top of 1 of the clinometer points and the other leg is placed in the slot in the adjacent point. Any expansion or contraction of either the instrument or the concrete causes only a very slight horizontal displacement of the leg that rests in the slot and this movement produces no error in the measurement being made.

After the legs of the clinometer are properly set in the gage points the instrument is carefully adjusted to a level position by rotating the knurled hand nut. When level, the micrometer dial is read. The clinometer is then moved 10 inches to the next gage point and the operation repeated. Any deflection of the slab due to load or to warping will change the relative elevation of the clinometer points and this change will be measured by the difference in the adjustments necessary to level the clinometer as indicated by differences in the readings of the micrometer dial before and after the deflection occurred. The operation is simply one of precise leveling along the line of installed points. While the micrometer dial reads directly in thousandths of an inch it was found practicable to estimate ten-thousandths. The design of the adjusting mechanism is such that thread wear and backlash cannot introduce an error in successive measurements.

Benchmarks or reference points completely independent of the pavement were used to fix the datum for the pavement surfaces.

TEMPERATURES MEASURED WITH THERMOCOUPLES

In practically all of the load tests it was necessary to reduce the influence of slab warping to a minimum. It was found that if the slab was kept shaded from all direct sunlight and covered with several inches of dry straw, the temperature differential between the upper and lower surfaces became negligible and the warping of the slab was so small that its influence on stress was not important. Therefore, these precautions were taken in all tests as a matter of regular procedure. The shade and straw covering are shown in figure 11.

Observations to determine the effects of the temperature and moisture conditions within and surrounding the test sections were started soon after the pavement was laid and have been continued to the present time. These observations included extensive temperature measurements, moisture determinations, measurements of the changes in size and shape of the slabs resulting from temperature and moisture variations, and measurements of the strains caused by these variations in various parts of the slab structure.

When the test sections were built a number of resistance coil thermometers were placed in the slabs at selected points to furnish the temperature data then thought necessary. The original installations proved to be inadequate in extent and several of the resistance coils ceased to function for some reason that could not be determined. It was found also that the coils used had a time lag in their operation that was very undesirable for the work to be done.

It became necessary to make other provision for measuring the temperatures in the concrete. The plan adopted was to build two small slabs of concrete of the same materials and proportions as were used in the test sections and to install in these copper-constantan thermocouples for temperature determination. These slabs were each 4 feet square and one was 6 and the other 9 inches in depth. The thermocouples were installed in the center of the slab area. Before placing the concrete two thermocouples were placed in the subgrade under each small slab at depths of 2 inches and ⅛ inch respectively and, as the concrete was being placed, additional thermocouples were placed at 1-inch intervals from the bottom of each slab to the top. With this installation it was possible to determine not only the differential existing between the upper and lower surfaces but also the complete temperature gradient from one to the other.

Thermocouples were also placed at the top and bottom surfaces of the four constant-thickness slabs.

The "average" temperature of the pavement slabs as used in connection with the expansion and contraction measurements was developed from the data obtained with the thermocouple installations in the small slabs. A pavement slab having a thickness of 6 inches or 9 inches was assumed to have an "average" temperature equal to the mean temperature of the small slab of the same thickness and the "average" temperature of sections having a thickness between 6 and 9 inches was obtained by interpolation, assuming a straight-line variation between the mean temperatures of the 6-inch and 9-inch slabs.

MICROMETERS USED TO MEASURE CHANGES IN LENGTH

Measurements were made to determine the extent of both the daily cycle and the annual cycle of dimensional changes in the slabs. These measurements served to show the magnitude of the changes in slab dimensions that were caused by the daily and annual variations in temperature and moisture content, and they also provided a means for determining the relative restraint to expansion and contraction offered by the various joint designs.

To determine the absolute changes in length of the slab sections, the movements of the slab ends with respect to fixed reference points were measured with a micrometer, while the degree of restraint offered by the joint designs was determined by comparing the movement at these joints with that at the free ends of the same slab.

The fixed reference points referred to were installed in concrete posts cast in heavy foundation blocks several feet below the surface of the ground, the posts themselves being completely protected from lateral earth pressure.

Figure 17 shows the 7-inch micrometer built for this purpose, together with the invar reference bar used for a standard of length in these measurements. The guaranteed coefficient of thermal expansion for this material is 0.8×10^{-6} per degree centigrade. Its change in length for air temperature ranges is so small that for the purpose of the tests its length could be considered as being constant throughout the year.

The measurements with this micrometer were made between the tips of conical gage points of stainless steel set horizontally in the upper ends of short steel posts cemented into the slab surface, one on either side of the joint (or slab end) and approximately 7 inches apart. These details can be seen in figure 17.

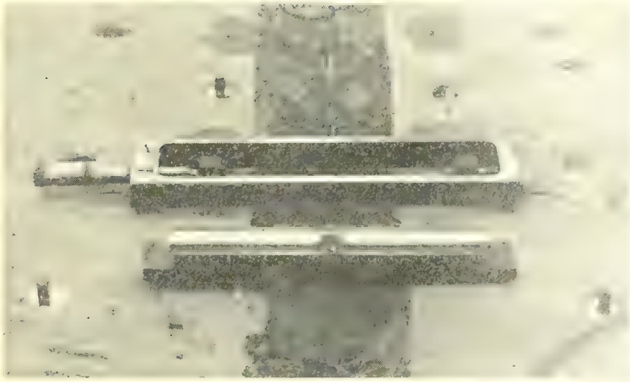

Figure 17.—The Special 7-Inch Micrometer Frame and the Invar Reference Bar Used for Measuring the Expansion and Contraction of the Test Sections.

Some additional data on the length changes occurring in the pavement slabs were obtained with 3 electric telemeters that were embedded in 3 of the slab panels at the time the concrete was placed. These instruments[7] were installed at mid-depth at the center of the longitudinal axis of three of the 10- by 20-foot panels. They were intended to provide data in connection with one of the designs but, because of certain difficulties that will be discussed later, they failed to do so. They did, however, furnish valuable information regarding elongation caused by both temperature and moisture.

ACTION OF SLABS DURING WARPING STUDIED

The magnitude of the temperature warping in the various sections was determined on numerous occasions over a period of about 3 years. Measurements were made to determine the warped shape of an entire 10- by 20-foot panel. The degree of restraint to free warping caused by the different joint designs was studied at selected points by means of measurements of warping over a limited area near the joint involved.

The necessary temperature data for these studies were obtained from the thermocouple installations and the shape of the warped surface was determined by clinometer measurements along the lines of points shown in figure 9. The measurements of warping with the clinometer were referenced to fixed points or bench marks set into the earth shoulders. Because of the time that was necessary to take readings around the entire perimeter of a 10- by 20-foot slab, frequently the shape of the slab changed sufficiently to develop a considerable error of closure. Care had to be taken to make these long series of measurements at a time when the conditions producing the warping were not changing too rapidly.

In the study of warping some attention was given to the strains in the concrete produced by the forces set up by the warping action of the slab itself and also to the relative strains produced in a slab of given design by a given load when the slab was both warped and unwarped. The procedure for the loading and strain measurement involved only one feature that was different from the rest of the strain measurements. To produce warping the straw cover was removed and the pavement was exposed to the direct rays of the sun for a number of the tests.

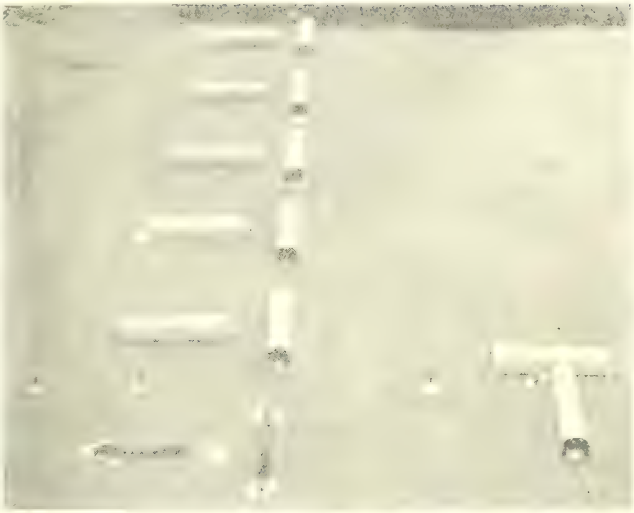

Figure 18.—A Strain Gage Installation for Measuring Strains Caused by Warping.

The very nature of these tests required a wide range of temperature and strain observations that were continuous over the complete warping cycle. It was thought desirable, therefore, to protect the strain gages from direct sunlight with small semicylindrical covers as shown in figure 18. These covers, to be described in a subsequent paper, permitted the free circulation of air around the gages but were so constructed as to resist heat absorption. The purpose of this protection was to keep the gages at the same temperature as the concrete in the pavement.

DIFFICULTY ENCOUNTERED IN MEASURING PRESSURE OF SLABS AGAINST THE SUBGRADE

A group of nine soil pressure cells was placed beneath the 6-inch and 9-inch slabs of constant thickness, arranged in the pattern of a 90° cross. These cells were installed in the subgrade with their diaphragm side down in carefully scraped recesses so that perfect bearing was obtained. The recesses were sufficiently deep to cause the back of the cell to be flush with the general level of the subgrade. The concrete of the slab was placed on these cells but no anchorage was provided to fix the cells to the concrete. The purpose of these installations was to obtain data on the distribution of a load to the subgrade by the two thicknesses of slab. Unfortunately, these data were never obtained as the cells under both slabs failed to record pressure before the load tests were made.

For a short time after the construction of the sections the cells operated and such pressure data as were obtained during this period indicated the normal fluctuations as the slab warped during the day. In the course of a few weeks the cells ceased to record pressure, indicating that a separation between the bottom of the slab and the back of the cells had occurred. Whether this was due to a settlement of the cells or a swelling of the subgrade that raised the slab more than it did the cells is not known. The cells were not embedded because it was desired to maintain the full flexural strength of the slab. Perhaps some anchorage attachment on the backs of the cells that would have held them to the slab without reducing the slab strength would have made a better installation, but this is by no means certain.

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[7] For a description see Technologic Paper No. 247, U. S. Bureau of Standards, A New Electric Telemeter, by Burton McCollum and O. S. Peters.

AUXILIARY TESTS MADE

A consideration, either theoretical or experimental, of the structural action of a concrete pavement slab lying on an earth subgrade, necessitates either assumptions regarding or a knowledge of the physical properties of the concrete and of the subgrade. Obviously, definite data developed by tests are to be preferred to any assumptions that may be made.

The auxiliary tests made in connection with this investigation were planned to develop information concerning:

(*a*) The concrete—
  1. Strength in compression and in flexure.
  2. Stress-strain relation in compression and in flexure.
  3. Effect of moisture content on the strength and elastic properties.
  4. Thermal properties.

(*b*) The subgrade—
  1. Resistance offered by the subgrade to horizontal slab movement.
  2. Resistance offered by the subgrade to vertical slab movement (or deflection) including an attempt to evaluate the support offered to the slab by the subgrade under the test sections.

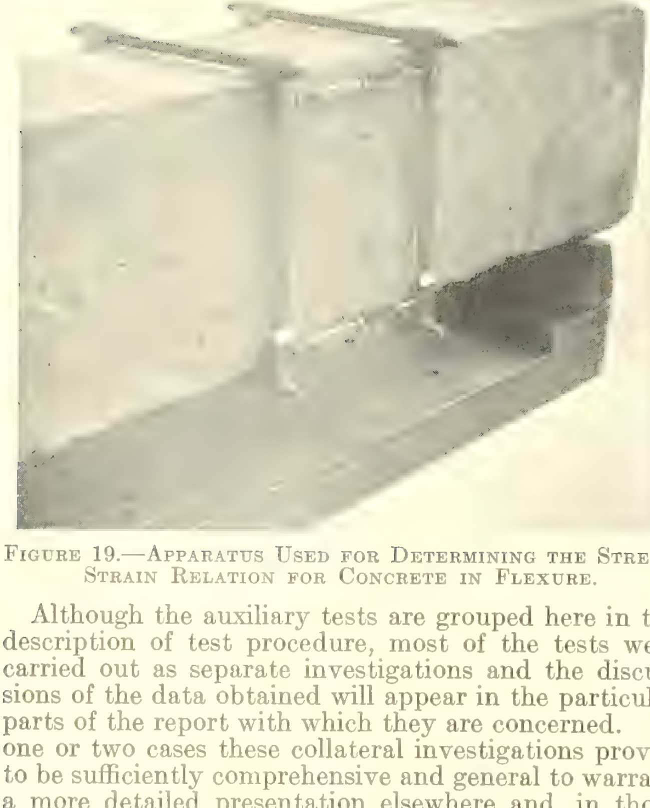

Figure 19.—Apparatus Used for Determining the Stress-Strain Relation for Concrete in Flexure.

Although the auxiliary tests are grouped here in the description of test procedure, most of the tests were carried out as separate investigations and the discussions of the data obtained will appear in the particular parts of the report with which they are concerned. In one or two cases these collateral investigations proved to be sufficiently comprehensive and general to warrant a more detailed presentation elsewhere and, in those cases, only the facts that have a direct bearing on the major research will be included in this report, leaving the detailed description of what was done to a separate report.

STRESS-STRAIN RELATION AND COEFFICIENT OF EXPANSION OF CONCRETE DETERMINED

The strength tests of the concrete were made to determine the ultimate strength in compression and in flexure so that safe working stress limits might be fixed.

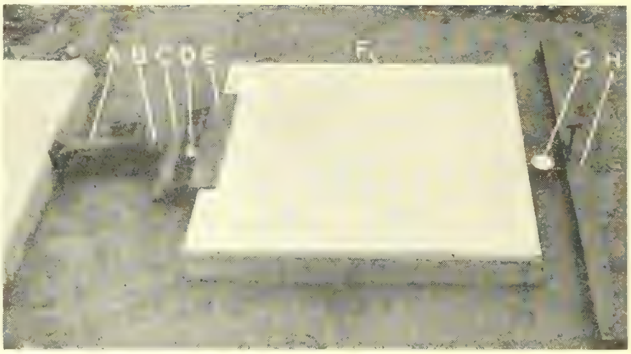

Figure 20.—Apparatus Used for Determining the Resistance of the Subgrade to Horizontal Movement of the Pavement.

The procedure followed in making these tests was simply that of good testing practice and included no unusual features. It will not be described therefore. The data obtained have already been given on page 148.

The determination of the stress-strain relations in compression and in flexure was a matter of considerable importance because of the direct application of the data to the analysis of the slab tests. Effort was made to have the tests comprehensive as to scope and precise as to technique to develop thoroughly reliable data. The stress-strain relation in compression was determined from tests on cores, using an extensometer of the Martens' type.[8] These cores were drilled from the small sections provided for the purpose and the program included tests on both wet and dry specimens.

For the determination of the stress-strain relation in flexure on the sawed beams, use was made of equipment designed in the bureau for this particular purpose and shown in figure 19. This apparatus consists of two frames that are clamped around the flexure specimen either side of the midspan and far enough apart to permit the installation of a recording strain gage near the top and bottom on each side of the beam. Each frame makes contact with the specimen at two points on each side of the beam. These points are small chisel-edged studs projecting from the inside of the frame directly opposite the points where the ends of the strain gages make contact with the frame and are held tightly to the specimen by tightening the transverse tie bolts of the frame. When the specimen is flexed the strain gages record the amount of length change that occurs between the frames on either side of the beam and in both tension and compression. The load was applied at the third points of the span and the deflection of the specimen at mid-span was measured with micrometer dials arranged on either side. The equipment for load application and for deflection measurement was omitted in figure 19 so that the details of the strain-measuring apparatus could be seen to better advantage.

Flexure specimens in both the wet and dry states were included in these tests. Since the concrete in the pavement slabs contained moisture and the moisture content of the concrete was assumed to vary, it seemed desirable to develop any information possible relative to the variations in moisture in the pavement slabs and also as to the effect of moisture condition on the physical properties of concrete similar to that used in making the slabs. The moisture content of the slabs was determined by the rather crude but direct

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[8] For a description see Handbook of Testing Materials, by Prof. Adolf Martens, 1st ed. 1899 (authorized translation by Gus C. Henning).

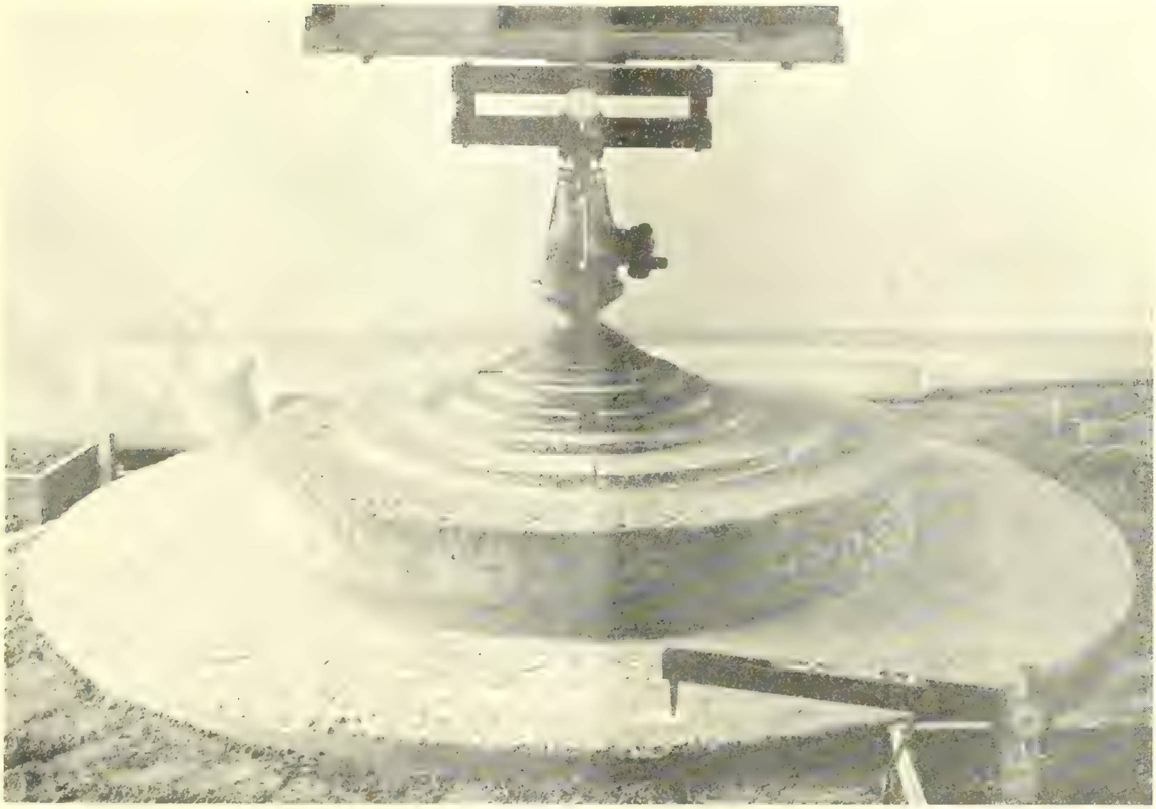

Figure 21.—Apparatus Used for Determining the Resistance of the Subgrade to Vertical Displacement.

method of weighing and drying fragments of concrete broken from the short sections of pavement provided for test specimens of all kinds. The moisture content of the test specimens was also determined by weighing.

The coefficient of thermal expansion of the concrete was determined by a method developed for these tests. Concrete of the same materials and proportions as were used in the pavement sections was placed in a cylindrical mold 12 inches in diameter and 24 inches high and made of a very light-gage sheet copper. This mold was in reality a large can with a watertight bottom and top. An electric telemeter was installed at the midpoint of the longitudinal axis of the cylinder. The concrete was introduced through an opening in the top of the can and as soon as the surface of the concrete was within about half an inch of the top of the mold this opening was sealed off by soldering on a cover plate. This effectively retained within the copper jacket all of the moisture originally in the concrete.

After the concrete had set and the heat of setting had been dissipated, the sealed specimen was placed in an insulated water bath, the temperature of which was placed at different levels within the range of normal air temperatures, and maintained at each until complete temperature equilibrium was established. The unit changes in length accompanying the various changes in temperature were measured with the embedded telemeter. This furnished a simple and apparently satisfactory method for the determination. The mass of concrete was large enough to be representative and the usual difficulties due to moisture changes in the specimen were avoided by using a watertight envelope.

RESISTANCE OF SUBGRADE TO HORIZONTAL AND VERTICAL MOVEMENT STUDIED

The tests made on the subgrade in place were planned with two objects in mind: First, to determine the character of the resistance that the subgrade offered to horizontal movement of the slab; and second, to find out what resistance the subgrade offered to vertical movement of the slab (such as deflection under load) and, if possible, to develop some means for evaluating this resistance in terms that would be applicable to pavement design.

The first tests were made with 4 slabs, each 4 feet square and 6 inches thick, placed on the same subgrade as the large test sections. The general method of test was to move these small slabs horizontally, very slowly, alternately forward and backward by total amounts that equalled approximately the annual cycle of expansion and contraction of the large pavement sections. The thrust necessary to cause horizontal movement and the magnitude of the displacement caused by the thrust were measured from the time that the first detectable movement took place until the total desired displacement had been attained.

Figure 20 shows the apparatus set up for one of these tests. In this figure, A is a jack used to develop the thrust, B is a spherical bearing block that controls the line of the thrust, C is a steel beam whose deflection, as indicated by the micrometer dial D, measures the magnitude of the thrust, E is the frame supporting the steel beam and the dial, F is the small slab, G is the micrometer dial that measures the horizontal displacement of the slab, and H is a rigid member used to support the dial G.

The second group of subgrade tests may be described generally as load-deflection tests on circular bearing plates in intimate contact with the subgrade. The diameters of the plates used were 2, 4, 6, 8, 12, 16, 20, 26, 36, 54, and 84 inches. The two larger sizes were concrete disks cast on the subgrade, the others were steel plates bedded in a ½-inch layer of mortar placed on the subgrade, but separated from it by a layer of waterproofed paper so that the moisture content of the soil would not be altered.

Figure 21 shows the loading equipment set up over the 84-inch bearing plate. It will be observed that the loads were applied on these plates in the same manner as on the pavement sections. For the very small plates a system of dead-load increments was used. Vertical displacements were measured with respect to fixed reference points by means of the clinometer shown in the figure. Generally these measurements were made at three points 120° apart around the periphery of the plates, although in some cases the measurements were made at the midpoint. In general the loads applied were such that a vertical displacement would be produced that approximated in magnitude the observed deflections of the pavement slabs. The deflection of a slab corner, for example, was found to be approximately 0.05 inch, the slab edge 0.02 inch, and the interior of the panel 0.01 inch for a load that did not overstress the concrete.

In making the tests on the subgrade, vertical displacements of 0.005, 0.010, 0.020, 0.035, and 0.050 inch were obtained in nearly all cases. For each displacement value, several loads were applied until a given load produced the same deflection each time it was applied. Each load was applied for 5 minutes and then released for 5 minutes before being applied again. In planning these tests it seemed desirable to arrange the procedure so that the subgrade would be subjected to the same conditions as would obtain under the loaded pavement slab, as nearly as possible. For this reason the rate of loading and the orders of magnitude of subgrade deformation were made to correspond very closely as noted above. The moisture content of the soil was determined before and after each test and protection from sunshine and rainfall was provided.

ROAD-BUILDING LIMEROCKS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by R. C. THOREEN, Assistant Highway Engineer

LIMESTONES include those rocks that are composed principally of calcium carbonate with varying amounts of other materials, chiefly silica, magnesia, alumina, and iron oxide. Their physical characteristics vary from the crystalline marbles and consolidated true limestones to the unconsolidated shell marls. This report is concerned with the less consolidated grades of limestone, known locally as "limerocks", that, because of their availability, are used extensively in the construction of road surfaces and base courses in the Southeastern States.

ORIGIN OF LIMEROCKS DISCUSSED[1]

Geologically, the limestones belong to the sedimentary group of rocks, or those that are composed of materials from older rocks that have undergone disintegration and have been redeposited either on land or in water by physical, organic, or chemical agencies. The following, more-detailed discussion of this process deals only with the formation of limestone in water, because the limerocks discussed in this report are chiefly of marine origin.

Lime (CaO) is widely distributed throughout the earth's crust. Because of its chemical activity it is always found in combination with other elements, chiefly as calcium carbonate ($CaCO_3$), in the form of limestone, calcite, and marine and fresh-water shells. It is not readily soluble in pure water, but is soluble in water charged with carbon dioxide (CO_2), resulting in carbonic acid (H_2CO_3).

Rain water becomes carbonic acid by absorbing carbon dioxide from the air or by contact with decaying vegetable matter. This acidulated water percolating through soil and rock materials takes calcium carbonate into solution as calcium bicarbonate $CaH_2(CO_3)_2$. While still in solution the lime is carried by streams and rivers to the ocean where conditions are favorable for deposition.

The deposition of calcium carbonate to form limestone is effected through two main processes: First, the activity of organisms that remove calcium carbonate from solution to form shells; and second, the removal of carbon dioxide by chemical and physical agencies, such as evaporation, aeration, and activity of bacteria and algae, with resultant supersaturation with and precipitation of calcium carbonate.

In an ideal case with both of these processes functioning, the sea floor becomes covered with more or less worn and broken shells and the remains of lime-secreting sea plants, bound together by an amorphous mass of calcium carbonate precipitated by different chemical reactions. If the bed becomes buried under newer sediments due to sinking of the sea floor, the pressure causes further consolidation and partial crystallization. If it becomes exposed by rising of the sea floor, rain water will leach out the calcium carbonate from the upper layers and redeposit and partially crystallize it in the lower layers, thus effecting further consolidation. The degree of consolidation has much to do with the classification of limestones, which differ widely in composition, hardness, texture, and color. The one property common to all limestones is the predominance of calcium carbonate.

With respect to physical appearance, the limerocks of the Southeastern States may be grouped as follows:

1. *Semicrystalline.*—Hard, rather compact limestone, originally soft but recrystallized and consolidated by the action of water. Examples are found in all limerocks that have been exposed to weathering and percolating water.
2. *Fossiliferous.*—Any limestone composed chiefly of fossil shells or other animal remains. All limerocks are fossiliferous in varying degrees.
3. *Shell.*—Limerock composed almost entirely of shells or shell fragments.
4. *Chalky.*—Partly consolidated limestone composed of microscopic shells and shell fragments.
5. *Oolitic.*—Limerock composed of tiny nodules of crystalline calcium carbonate held together by a calcareous cement.
6. *Sandy.*—Limerock into which sand has been incorporated by the action of water currents and waves.
7. *Cherty or flinty.*—Limerock containing nodules or bands of chert or flint. Chert is amorphous silica formed from spicules of sponges and other siliceous matter by the action of ground water.
8. *Marl.*—An indefinite term applied to any soft, earthy mass containing varying quantities of lime, clay, sand, and carbonaceous material. The lime content frequently is in the form of marine or fresh-water shell fragments.

LOCATIONS AND CHARACTERISTICS OF LIMEROCKS DESCRIBED

The limerocks are found in greatest abundance throughout Florida and in the southern portions of Georgia and Alabama. The principal workable deposits in Florida are known as the Ocala, Marianna, Miami Oolite, Tampa, Glendon, and Coquina formations, and also include extensive deposits of undifferentiated marls. The physical characteristics and general locations of these deposits are as follows:

1. *Ocala.*—The Ocala formation consists of a cream-white, soft, porous, granular limestone that bleaches to a chalk-white on exposure (see fig. 1). Some portions are hard and semicrystalline, and in some localities it contains nodules and layers of chert. On the whole it is very uniform in texture and composition, containing as high as 99.6 percent calcium carbonate.

Although the Ocala limestone presumably underlies the whole State to a thickness of more than 400 feet, it is exposed over a comparatively limited area about 50 by 150 miles in extent in the northwestern portion of the peninsula, adjacent to and paralleling the Gulf of Mexico, and in a small area in western Florida just below the Alabama line.

2. *Marianna.*—The Marianna is a very pure, soft, chalk-like limestone, cream-yellow when fresh and chalk-white when bleached by exposure. Recent excavations have revealed that it contains a considerable amount of argillaceous material scattered throughout. The Marianna overlies the Ocala formation to a known thickness of 33 feet. It is exposed over a small area

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[1] This discussion of the origin of limerocks and the distribution of the Florida deposits is based on A Preliminary Report on the Limestones and Marls of Florida, by tuart Mossom, sixteenth annual report, Florida Geological Survey, 1925.

surrounding the town of Marianna in Jackson County, Fla.

3. *Glendon.*—The Glendon limestone consists of minute fossils bound together by amorphous lime material. It is much more compact and not as powdery as the Ocala limestone. The outcroppings of this rock cover a considerable area in western Florida and extend into southeastern Alabama.

4. *Tampa.*—The Tampa limestone varies from a hard, semicrystalline, cream-colored or light-gray rock to a rather soft, amorphous material containing scattered masses of dense, crystalline limestone. The principal deposits are located in the western portion of the peninsula near the city of Tampa, also in the extreme northeastern portion of the peninsula, and to a limited extent in western Florida.

5. *Miami Oolite.*—The typical rock of this formation is a soft, white, pure (95 percent calcium carbonate), oolitic limestone with occasional irregular layers of calcite (see fig. 1). In places rounded grains of white sand are intermixed, sometimes occurring in lenses or pockets. The rock hardens on exposure to air and water. Miami Oolite, known locally as "Ojus" rock, occurs in a rather narrow strip along the coast of southeastern Florida.

6. *Coquina.*—The Coquina limestone occurs in three principal phases. The first is composed entirely of small, clean shells and shell fragments, usually unconsolidated but with hard ledges of firmly cemented shells near the top of the deposit (see fig. 1). The second phase consists of finely crushed shells closely cemented into a hard, compact rock. The third phase contains finely crushed shells and a large quantity of sand grains, cemented together by the calcium carbonate of the shells. In the latter phase it is more a calcareous sandstone than a sandy Coquina. The Coquina deposits are located chiefly in a narrow strip along the eastern coast of the peninsula.

7. *Marls.*—Marl deposits of various compositions are distributed over an extensive area in the lower third of the peninsula and in scattered localities in northern and western Florida.

In Georgia the principal limerock deposits are found in a comparatively narrow strip extending from the southwestern corner of the State in a northeasterly direction to the Atlantic coast. The limerocks in most of this strip are of the Jackson group, of which Ocala limestone is the upper formation, and therefore they are somewhat similar to Ocala limestone in physical characteristics. The limestones in the northern portion of this strip are principally marls that are also distributed in scattered localities throughout the southeastern portion of the State.

Outcroppings of the Ocala, Glendon, and Marianna formations are also found in Alabama. The Glendon limerock appears as an extension of the Florida deposits in the southeastern portion of the State. The Ocala and Marianna formations are found in the extreme southeastern corner of the State as extensions of the Florida deposits, and they also appear in limited areas in the southwestern portion of the State east of the Tombigbee River. As in Florida and Georgia, marl deposits are also distributed in scattered areas throughout the southern portion of the State.

ROAD CONSTRUCTION METHODS USING LIMEROCK

Mining of the limerocks is all open-pit work after the overburden of soil has been removed by power shovels (see fig. 2). Although the rock is sometimes so soft that it can be scraped from the face of the pit by the shovels, it is usually fractured and loosened by blasting to facilitate handling. It is conveyed to crushers, crushed to the fineness required, and either loaded directly or stored. Although in most of the deposits the limerock is soft and powdery, crushing is usually necessitated by the occurrence of harder masses. Most pits are worked to the depth of the water table. However, Miami Oolite is mined by means of dredges to a depth of as much as 30 feet below the water table.

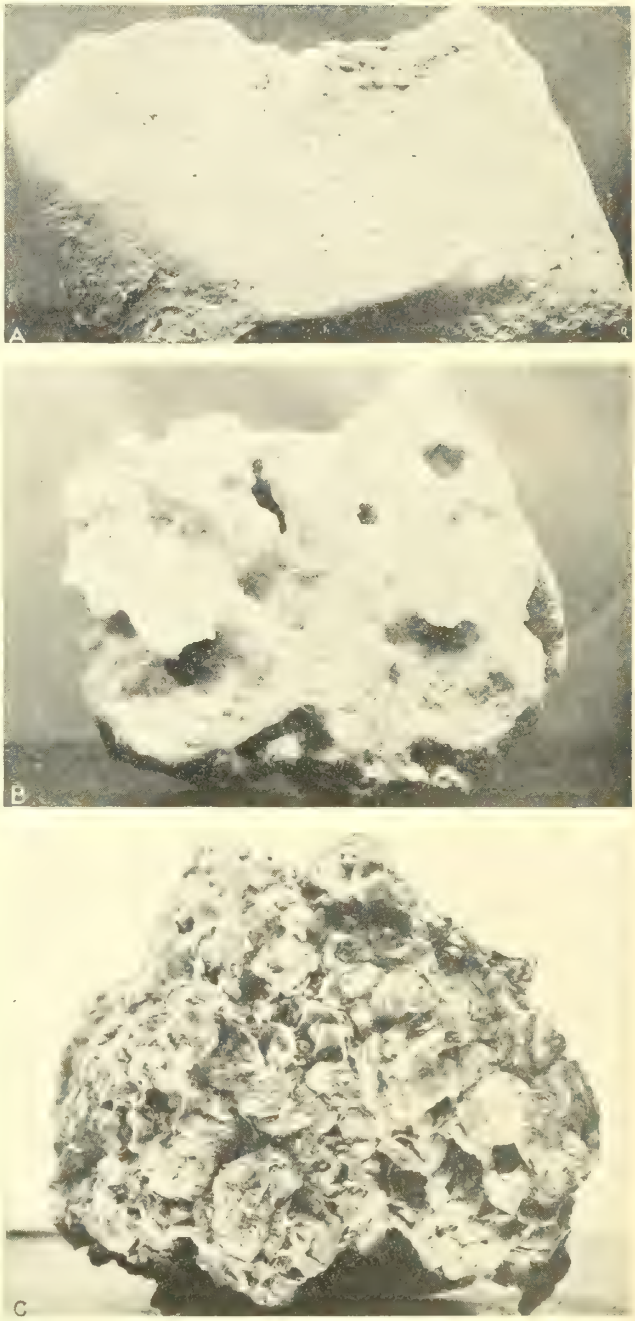

Figure 1.—Typical Samples of Limerocks: A, Ocala Limerock. The Left Half is Hard and Semicrystalline, the Right Half is Soft and Porous. B, Miami Oolite; C, Shell-Phase Coquina Limerock.

Some of the harder, semicrystalline portions of limerocks, of which limited quantities occur in a number of the principal formations, are suitable for use in mac-

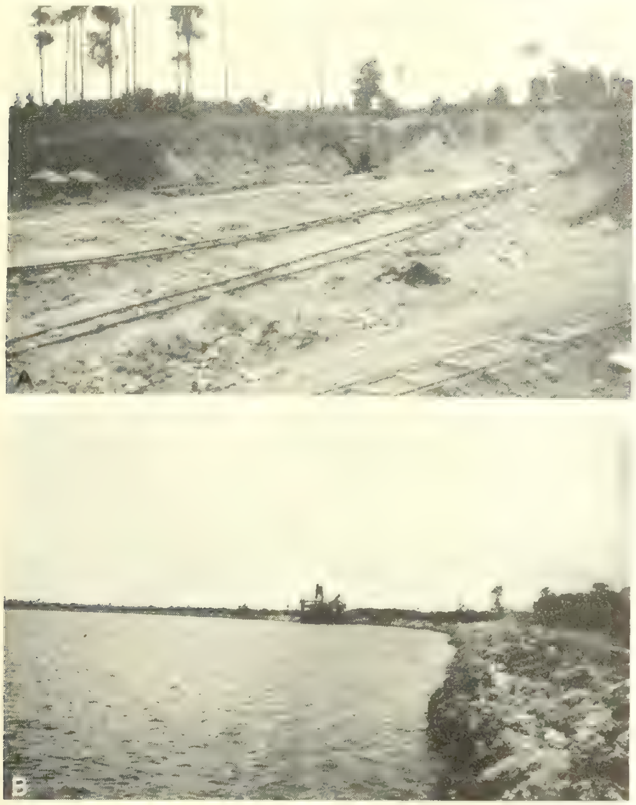

FIGURE 2.—METHODS OF MINING LIMEROCKS: A, OPEN-PIT MINING OF OCALA LIMEROCK; B, DREDGING OF MIAMI OOLITE.

adam surfacing or as concrete aggregate. The bulk of the limerocks are too soft for these purposes, however, and are used in granular form in the construction of base courses and low-type road surfaces.

Limerock base courses are usually constructed in two layers. The construction procedure, while subject to minor variations depending upon the type of limerock being used, is substantially as follows:

Side forms of sufficient height to confine the uncompacted material are placed (see fig. 3). Final preparation of the subgrade is completed by means of templets. The limerock first arriving is dumped adjacent to and then spread over the prepared subgrade to a depth equal to approximately half the thickness of the finished base. Subsequent loads are hauled over and dumped on material already placed and spread on the subgrade as at the start of construction, care being taken at all times to avoid dumping the rock directly on the subgrade.

During the dumping and spreading operations the limerock is thoroughly saturated with water unless it is sufficiently moist when received. Immediately after spreading, the limerock is thoroughly compacted by rolling. Not more than 1 day's spread of material is placed before the second course is started.

Before placing the second layer, the first layer is bladed to a uniform surface and thoroughly watered to obtain bonding between the two layers. The material for the second layer is spread to a depth sufficient to insure the required thickness of finished base. It is then thoroughly watered and rolled until the entire base is dense and unyielding.

After the second course has been rolled, the entire urface is scarified, shaped to the desired cross section, and again watered and thoroughly rolled. Rolling is continued until the entire depth of base course is bonded and compacted and its surface is true to grade and cross section.

The surface is then checked with a templet and straightedge, and the thickness of the base is checked by borings at regular intervals. Any deficiencies in smoothness and thickness are corrected, and the base course is then opened to traffic for a curing period.

After the curing period the base is given a light blading to correct any pitting caused by traffic; following this a bituminous prime coat is applied. After the prime coat has cured for a short period, the bituminous wearing course is placed (see fig. 4).

LIMEROCKS GROUPED ACCORDING TO QUALITY

For the purpose of determining the tests most suitable for distinguishing between the satisfactory and unsatisfactory varieties of limerock, samples representative of conspicuous performance and of roads under different climatic and traffic conditions were tested in laboratories of the Bureau. The tests ordinarily made on similar road-building materials were performed.

Samples were obtained from quarries or pits that supplied material for base courses of known performance and from base courses actually constructed in Florida, Georgia, and Alabama. These samples were furnished by the State highway departments. Information on the quality or performance of the materials represented was supplied by the highway departments and by a Bureau representative.

The various degrees of quality or performance of the materials investigated have been designated by the terms "excellent", "good", "fair", or "poor"

The limerocks considered as excellent provide stable base courses under practically all conditions They have no plasticity and do not shrink appreciably on drying. They are readily machined and finished, and practically any faults resulting from errors in construction can be corrected without detriment to the quality of the material.

The limerocks considered as good are usually satisfactory if ordinary care is observed in construction. These materials have little shrinkage and are only slightly plastic. They provide a dull, closely-knitted surface when wetted and rolled, and are not slippery when wet. Excessive watering during construction, however, may result in their breaking down under manipulation to the extent that proper curing cannot be effected. Also, hauling over such materials when newly laid sometimes prevents bonding.

The limerocks classified as fair are similar in most respects to the good varieties and are just as capable of giving satisfactory service when first-class construction methods are used. However, they are less resistant than the good limerocks to failure in the presence of moisture such as would result from continued wet weather.

The limerocks considered as poor have never given entirely satisfactory results as base course materials. Field observations show that these materials are highly plastic and are slippery when wet. In finishing base courses constructed of some of these limerocks a scum is formed, often to a depth of one-half inch. This scum shrinks and cracks on drying and must be removed by blading. None of the poor limerocks can be used except when dry. They cannot be used with any assurance of satisfactory results except possibly in the lower layer of base courses on unusually good sandy subgrades, or when combined with at least an equal proportion of sand or other granular material.

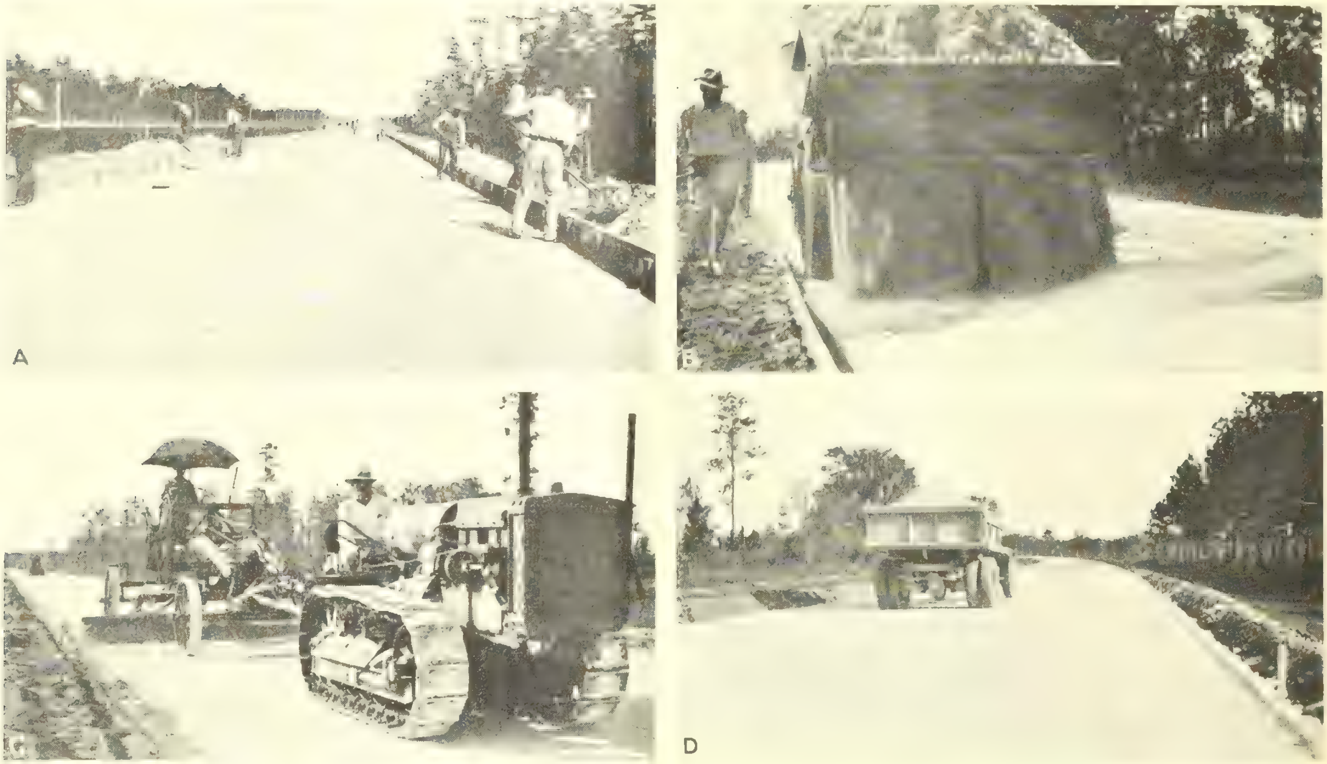

FIGURE 3.—BASE-COURSE ROAD CONSTRUCTION OPERATIONS USING LIMEROCK; A, SUBGRADE PREPARATION. THE SIDE FORMS ARE IN PLACE. B, DUMPING, SPREADING, AND WATERING LIMEROCK; C, BLADING AND FINISHING OPERATIONS; D, FINISHED BASE COURSE READY FOR PRIME COAT.

The materials investigated were grouped according to the foregoing designations, the groups being numbered consecutively from 1 to 4 in the order of their discussion.

VARIOUS LABORATORY TESTS PERFORMED

The laboratory examinations of the limerock samples included chemical analyses, mechanical analyses, the Page tests, and determinations of the subgrade soil constants.

The chemical analyses disclosed the percentages of calcium carbonate, magnesium carbonate, and combined silica, alumina, and iron oxide.

The Page tests, the procedures for which are described in United States Department of Agriculture Bulletin 347, disclosed the cementing value and time of slaking.

The subgrade soil constants determined for the limerocks were liquid limit, plasticity index, shrinkage limit, shrinkage ratio, centrifuge moisture equivalent, field moisture equivalent, volumetric change, and flocculation factor.

The significance of all these constants, except the flocculation factor, and the procedures for their determination are discussed in detail elsewhere.[2]

The flocculation factor is determined as follows: Five cubic centimeters (absolute volume) of the powdered material are thoroughly dispersed in 39 cc of distilled water and 1 cc of chemical deflocculent in a 50-cc glass-stoppered graduate and permitted to settle. The flocculation factor is the ratio of pores to solids in the accumulated sediment at the end of 24 hours.

The tests were performed on material passing a no. 40 sieve, as it was found that with few exceptions the samples could be reduced to this size with little effort. This material may be considered representative of the fine or binder portions of the base courses produced by the crushing action of the rolling and other manipulation during construction. Whether or not this is entirely true does not invalidate the results for comparative purposes, since the same method of preparation was used for all samples.

Chemical composition.—The results of the chemical analyses given in table 1 show that the samples of excellent limerocks contained a high percentage of calcium carbonate, averaging 98.3 percent. However, table 1 shows that the fair limerocks contained an average of 97.1 percent calcium carbonate, or practically as much as the excellent limerocks contained. On the other hand, the good limerocks (excluding sample no. 24, which is obviously not representative of the chemical composition of this group) contained considerably less calcium carbonate than the excellent limerocks, averaging 91.1 percent. Moreover, the poor limerocks contained practically the same amount of calcium carbonate as the good limerocks.

Likewise, the percentages of combined silica, alumina, and iron oxide did not vary according to the quality of the material, these percentages for the good limerocks being practically the same as those for the poor limerocks. The average magnesium carbonate contents of the inferior materials were slightly greater than those of the other groups, but the variation was not consistent enough to serve as a means of identification.

It is thus apparent that the chemical analysis is not an efficient indicator of the quality of different grades of limerock in general. However, it should be stated that a knowledge of the calcium-carbonate content has been found by field experience to be a satisfactory guide

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[2] See PUBLIC ROADS, vol. 12, nos. 4, 5, and 8, June, July, and October 1931.

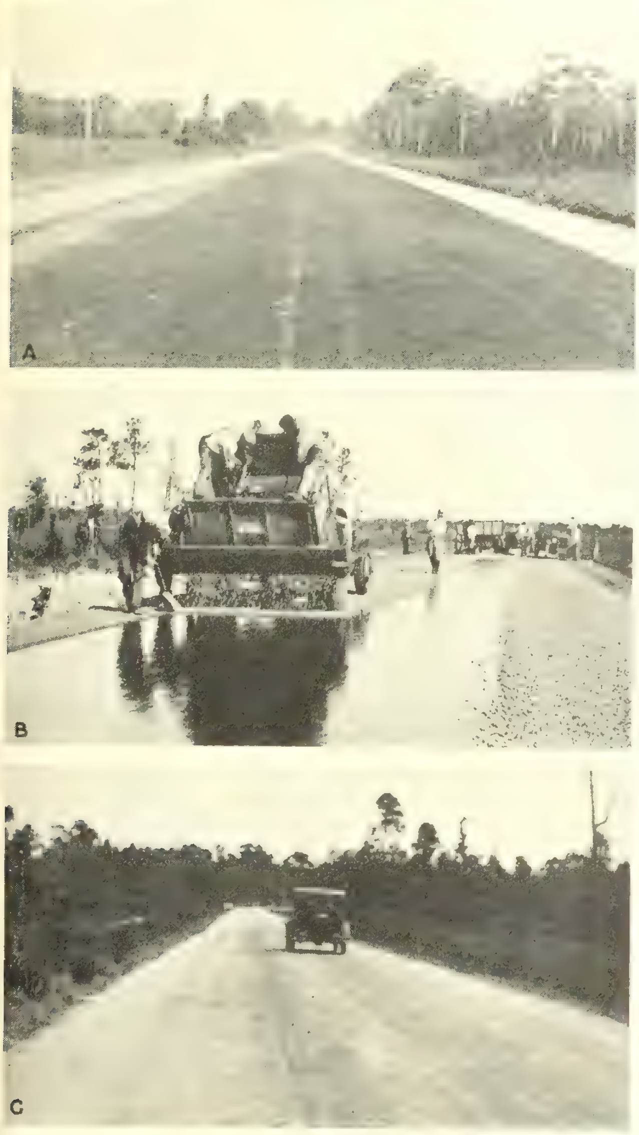

Figure 4.—A, Completed Limerock Base Course With Prime Coat; B, Applying Surface Treatment; C, Surface Treatment Completed and Highway in Use.

Table 1.—*Chemical composition, cementing value, and time of slaking of limerocks*

Sample no.	Chemical composition			Cementing value	Time of slaking
	Silica, alumina, and iron oxide	Calcium carbonate	Magnesium carbonate		
	Percent	*Percent*	*Percent*		*Minutes*
GROUP 1. EXCELLENT					
6	0.40	98.66	0.87	14	60+
8	.50	98.66	.76	14	15
11	.65	98.04	.76	11	10
13	.90	98.13	.76	12	60+
14	.90	98.20	.83	53	16
15	1.35	97.85	.80	15	11
Average	.78	98.26	.80	20	
GROUP 2. GOOD					
16	8.40	90.89	0.72	87	10
17	3.50	96.07	.68	79	13
18	11.00	87.50	.61	88	13
19	9.10	90.00	.83	71	13
20	8.80	90.00	.72	75	11
21	11.10	87.76	.83	110	20
22	9.60	88.75	.68	57	11
23	9.20	89.55	.87	80	18
24	[1] 30.80	[1] 67.50	[1] .61	102	20
25	3.70	95.00	.76	50	14
26	7.20	91.78	.71	86	10
27	4.45	94.82	.76	95	23
Average	7.82	91.10	.74	83	15
GROUP 3. FAIR					
31	2.65	95.34	1.51	168	30
33	.50	98.75	.83	32	60+
36	3.20	95.63	.76	11	60+
37	1.65	97.14	.91	34	5
38	.35	98.66	.80	39	60+
Average	1.67	97.10	.96	57	
GROUP 4. POOR					
43	10.00	88.32	0.68	387	9
44	9.45	87.68	1.44	101	25
45	9.40	88.04	.68	229	9
46	7.90	89.73	1.02	210	18
47	8.25	90.00	.98	149	16
48	7.45	90.45	1.25	110	17
49	8.30	89.38	.76	249	8
50	6.80	91.16	.91	115	15
51	7.35	90.45	.95	107	12
52	7.90	90.36	.83	235	22
53	6.65	91.60	.91	67	11
54	10.00	88.75	.76	196	9
Average	8.29	89.66	.93	180	14

[1] Excluded from averages.

in the selection of materials within certain given deposits or formations.

Cementing and slaking values.—The lack of correlation between the cementing value and reported performance is at once apparent from the wide variation of cementing values within each of the groups. Because of this variation the average value for each group has little significance. It is interesting to note, however, that the average cementing value of the poor limerocks was nine times that of the excellent limerocks. The usual interpretation of this test, that the higher the cementing value the better the material, not only did not apply in this instance but was completely reversed. The erratic results obtained indicate that the cementation test, however interpreted, is a very uncertain method for distinguishing between satisfactory and unsatisfactory limerocks.

The average times of slaking for the poor limerocks were practically equal to those for the good limerocks. Also, there was no consistent difference between the slaking times for the samples of excellent and fair limerocks. Consequently, this test likewise did not serve to differentiate between the different grades of limerock.

Mechanical analyses.—The mechanical analysis of a soil yields information as to the presence of materials varying not only in size but also in character, since the different fractions are not merely the results of mechanical reduction in size of any one material such as sand, but are also the product of chemical reactions caused by weathering, oxidation, and the like. The mechanical analysis of a homogeneous material such as limerock, in contrast, merely reflects the degree to which the material was crushed in preparation, and therefore does not have the same significance as for a soil.

Therefore, the purpose of grinding the limerocks in preparation for test was not, as in the case of soils, to effect separation of particles already differing in size and character, but only to reduce the mass of material to such size as to make possible the performance of the physical tests.

A number of mechanical analyses were performed, however, because it was desired to determine whether or not limerocks differing in quality would break down to different degrees of fineness under the uniform method of preparation used, and whether differences in quality thus would be indicated by the mechanical analysis. The similarity in the gradings of the samples representing the excellent limerocks to those representing the fair quality limerocks indicates that the degree of fineness does not vary substantially with the quality of material and, therefore, that the mechanical analysis is not significant for identification purposes. (See table 2.)

GOOD LIMEROCKS HAD LOW PLASTICITY INDEXES

Subgrade soil constants.—The results of the subgrade soil tests, shown in table 3, show that the shrinkage limits and shrinkage ratios were not consistently different for the various grades of limerock, and that volumetric change on drying out after being wetted to the field moisture equivalent was either entirely absent or so small as to have little significance. Although some shrinkage of the poorer grade limerocks was observed in the field, it is evident that the shrinkage is not always reflected in the laboratory tests and therefore that the usual method of determining shrinkage is of little value in limerock identification.

Likewise, the liquid limit considered apart from its relation to the other tests, while, on the average, increasing with decreasing quality of limerock, did not vary consistently for the different grades when individual determinations are considered.

TABLE 2.—*Mechanical analyses of limerocks*

GROUP 1. EXCELLENT

Sample no.	Particle size smaller than—			
	0.42 mm	0.05 mm	0.005 mm	0.001 mm
	Percent	*Percent*	*Percent*	*Percent*
1	100	38	16	4
2	100	57	17	5
3	100	56	21	3
4	100	56	22	4
5	100	45	19	6
7	100	34	16	5
9	100	50	22	6
10	100	45	22	8
12	100	42	20	6
Average	100	47	19	5

GROUP 3. FAIR

Sample no.	0.42 mm	0.05 mm	0.005 mm	0.001 mm
31	100	70	21	8
33	100	64	22	4
37	100	46	21	4
38	100	74	28	4
39	100	48	22	6
40	100	51	24	6
41	100	40	21	8
42	100	40	20	4
Average	100	54	22	6

The results show that the poor limerocks had higher plasticity indexes than any of the good or fair quality limerocks and that, without exception, the excellent limerocks had no plasticity whatever. In addition, they show that the centrifuge and field moisture equivalents of the fair and poor limerocks were on the whole greater than those of the excellent and good limerocks. The variation thus shown is highly significant in that the difference in water-absorbing properties of the good and fair limerocks thus indicated corresponds to the difference in their reported field performances in the presence of water, and thus offers a basis of distinction between these two groups.

TABLE 3.—*Subgrade soil test constants for different limerocks*

GROUP 1. EXCELLENT

Sample No.	Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Moisture equivalent		Flocculation factor	Volumetric change
					Centrifuge	Field		
1	26	0	35	1.4	21	22	1.3	0
2	25	0	29	1.5	17	20	1.3	0
3	25	0	28	1.5	23	24	1.4	0
4	25	0	27	1.5	21	23	1.3	0
5	22	0	24	1.6	16	20	1.2	0
6	20	0	26	1.6	17	20	1.2	0
7	20	0	26	1.6	15	19	1.1	0
8	20	0	25	1.6	16	20	1.2	0
9	19	0	23	1.6	15	18	1.1	0
10	19	0	22	1.7	19	17	1.3	0
11	18	0	23	1.6	15	19	------	0
12	18	0	22	1.7	14	17	1.0	0
13	18	0	21	1.7	15	18	1.2	0
14	17	0	22	1.7	15	18	------	0
15	17	0	21	1.7	17	16	1.0	0
Average	21	0	25	1.6	17	19	1.2	0

GROUP 2. GOOD

Sample No.	Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Centrifuge	Field	Flocculation factor	Volumetric change
16	23	0	23	1.6	15	21	1.2	0
17	22	0	19	1.8	15	20	1.2	2
18	21	6	21	1.7	16	18	1.3	0
19	21	5	21	1.7	20	20	1.6	0
20	21	5	21	1.7	19	22	1.6	2
21	21	5	21	1.7	17	20	1.5	0
22	20	5	19	1.8	16	19	1.5	0
23	19	6	18	1.8	16	15	1.4	0
24	19	5	17	1.8	18	17	1.2	0
25	19	4	19	1.7	16	18	1.5	0
26	18	4	16	1.8	15	16	1.3	0
27	18	0	25	1.6	12	20	------	0
Average	20	4	20	1.7	16	19	1.4	(1)

GROUP 3. FAIR

Sample No.	Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Centrifuge	Field	Flocculation factor	Volumetric change
28	27	7	24	1.6	22	23	1.5	0
29	26	7	23	1.7	23	23	1.4	0
30	26	6	25	1.6	22	23	1.5	0
31	26	5	26	1.5	28	30	1.9	6
32	25	6	22	1.6	21	23	1.5	2
33	25	5	26	1.6	27	22	1.7	0
34	25	5	24	1.6	23	24	1.2	0
35	25	4	22	1.6	19	25	1.3	5
36	24	5	24	1.6	21	26	1.6	3
37	24	5	24	1.6	21	25	1.3	2
38	24	3	26	1.6	30	24	1.9	0
39	23	3	27	1.5	23	------	1.4	------
40	22	3	26	1.6	23	21	1.5	0
41	22	0	29	1.5	20	------	1.2	------
42	20	0	26	1.6	19	------	1.2	------
Average	24	4	25	1.6	23	24	1.5	

GROUP 4. POOR

Sample No.	Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Centrifuge	Field	Flocculation factor	Volumetric change
43	34	17	21	1.7	31	24	2.3	
44	31	13	24	1.6	27	23	2.0	
45	30	15	19	1.7	23	22	2.1	
46	30	10	24	1.6	26	22	1.8	
47	28	11	21	1.7	24	22	1.8	
48	28	10	24	1.6	28	24	1.9	
49	28	9	22	1.7	26	22	------	
50	25	9	19	1.8	23	21	1.8	
51	25	8	21	1.7	23	20	2.0	
52	24	8	19	1.8	21	20	1.4	
53	24	8	19	1.7	26	20	1.4	
54	23	8	16	1.8	18	17	1.6	
Average	28	11	21	1.7	25	21	1.8	

[1] Negligible.

Since the centrifuge and field moisture equivalent are apparently of like significance for this purpose, i would seem desirable to include only the simpler of th two tests, the field moisture equivalent, in the testin procedure.

The test results also show that, in general, th flocculation factors increase with decreasing quality material.

CONCLUSIONS

The test results indicate that the tests of greatest value for predetermining the quality of road-building limerocks are the plasticity, the field moisture equivalent, and the flocculation tests. While present information does not warrant the establishment of rigid limiting values, a plasticity index of 0 to the exclusion of all other determinations appears sufficient to indicate those limerocks that are likely to perform satisfactorily as base-course material under practically all conditions; a plasticity index from 1 to 7 and a field moisture equivalent not exceeding 20 indicate limerocks that will perform satisfactorily in carefully constructed base courses under average conditions; a plasticity index from 1 to 7 and a field moisture equivalent greater than 20 indicate limerocks that will perform satisfactorily in carefully constructed base courses under fairly dry conditions; and a plasticity index of 8 or more indicates limerocks that are likely to prove troublesome.

Use of the foregoing tests does not eliminate the desirability of using the chemical analysis in certain cases, such as those in which the quality of material within a given deposit or formation has been found to vary with the calcium carbonate content.

The flocculation test seems of sufficient significance to be useful for the preliminary field examination of limerocks. A flocculation factor exceeding about 1.9 will indicate material unsuitable for base-course construction, thus eliminating the necessity for any further tests. Of course as is shown, for example, by the test results on samples no. 52 and 53 (see table 3), a flocculation factor under 1.9 will not necessarily indicate a satisfactory material and must be supplemented by plasticity and field moisture equivalent tests for more definite identification. Use of the flocculation test in the field, however, will in some cases eliminate the inconvenience of sampling and transporting materials to a laboratory for further testing.

NEW SPECIFICATIONS FOR HIGHWAY MATERIALS AND HIGHWAY BRIDGES AVAILABLE

A revised edition of the Standard Specifications for Highway Materials and Methods of Sampling and Testing is now available from the American Association of State Highway Officials, 1220 National Press Building, Washington, D. C.

This publication contains standard specifications for portland cement, high-early-strength portland cement, different grades of bituminous materials, aggregates for various highway uses, steel reinforcement, corrugated metal pipe culverts, wire rope and fittings for guard rails, premolded asphalt plank, reinforced concrete culvert pipe, and paint for traffic lines. This material covers 64 pages. Two hundred and forty-three pages are devoted to standard methods of sampling and testing highway materials. Included in this material are nine new methods and tests relating to sampling and testing subgrade soils. The price of the publication is $2 per copy.

The new edition of Specifications for Highway Bridges adopted by the American Association of State Highway Officials will be available within a short time. The sections of this publication are General Provisions, Materials, General Construction, Special Construction, Design, Appendices containing tables of moments, shears, etc., for H–20 loading and a guide to grading structural timbers, and arc welding metal bridge structures. The price of this publication is $2 per copy.

The Bureau of Public Roads has cooperated with the association in preparing both of these publications and the specifications are recommended by the Bureau for general use in highway construction. Copies are not available from the Bureau.

HIGHWAY RESEARCH BOARD TO MEET IN DECEMBER

The Fifteenth Annual Meeting of the Highway Research Board of the National Research Council will be held in Washington, D. C., on December 5 and 6, 1935. A program of reports on research investigations is to be announced in the near future.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF SEPTEMBER 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 7,230,252	$ 3,660,004	$ 469,752	394.9	$ 1,690,593	$ 287,749	$ 1,227,477	84.9		$ 17,945			$ 414,747
Arizona	3,855,555	1,381,051	5,[illegible],449	3,829,744	681,541	381.6	783,475	15,039	676,051	13.3				$ 10,772	23,459
Arkansas	3,334,167	1,714,000	4,147,331	2,802,924	640,429	185.9	1,567,696	492,798	935,379	80.9		32,191	0.1	38,445	106,001
California	7,912,928	3,713,643	12,045,142	7,790,341	1,040,465	395.0	3,257,955	121,228	2,525,800	52.8		11,203	.5	1,360	136,175
Colorado	3,437,265	2,424,504	5,879,938	3,359,613	2,286,625	285.2	219,568	77,653	128,808	7.6					3,072
Connecticut	1,404,213	607,500	1,592,908	1,398,014		30.8	670,946		554,726	7.2				6,199	52,774
Delaware	877,566	461,697	1,355,369	877,566	456,600	48.8	1,102		1,102						3,996
Florida	2,469,369	1,116,600	3,892,937	2,373,654	687,741	147.2	307,215	59,479	220,479	9.2		184,895	2.2	36,236	23,484
Georgia	5,045,592	2,556,745	5,681,091	4,301,508	1,128,394	377.6	1,323,490	585,971	654,495	50.8	$ 5,136	19,417	.3	152,977	754,439
Idaho	2,166,858	1,131,910	2,823,180	2,158,872	563,910	231.6	353,991		343,338	16.5		1,670	.1	7,986	222,992
Illinois	4,408,827	2,408,778	3,595,766	3,048,230	490,658	61.3	3,052,792	1,336,281	1,715,696	45.9		202,424		24,316	
Indiana	5,018,921	2,688,632	4,631,907	4,360,519	105,148	129.1	3,127,293	582,353	2,491,450	152.4		12,920		76,049	79,114
Iowa	5,025,830	1,963,361	7,174,580	4,986,630	1,697,936	421.9	319,000	39,200	264,440	17.5					985
Kansas	5,044,802	2,354,131	6,180,011	5,004,394	997,730	670.1	1,386,053	31,530	1,331,976	92.8		24,425	.9	8,878	
Kentucky	3,751,605	1,302,209	4,226,537	3,512,269	451,162	307.1	1,035,501	182,976	723,447	39.3	8,570	5,000	9.0	47,790	122,599
Louisiana	2,693,135	1,380,419	3,093,008	2,481,839	93,648	79.4	1,088,499	34,283	1,047,066	26.2	40,221	23,404	1.1	136,792	216,302
Maine	1,567,012	782,195	2,163,254	1,544,248	588,897	57.5	197,482	5,179	192,289	6.8				17,585	1,010
Maryland	1,782,263	332,836	1,222,286	1,097,249	123,526	21.7	724,472	594,801	129,672	16.1		28,558	1.4	90,213	51,081
Massachusetts	1,101,716	1,582,874	2,075,114	1,048,966	530,306	47.9	575,991	52,687	523,304	9.7		499,386	2.1	63	29,877
Michigan	6,051,533	3,126,284	7,264,721	5,938,494	955,100	292.3	2,235,900	108,800	2,102,336	109.7		68,848	3.1	4,239	
Minnesota	4,561,011	2,533,733	7,021,257	4,461,058	2,290,026	1,066.3	311,885	93,673	180,120	32.4		3,074		6,280	60,512
Mississippi	3,489,337	2,832,182	6,104,844	2,853,429	837,683	321.9	2,499,073	556,664	1,556,044	133.3	20,193	64,295	4.1	59,051	374,160
Missouri	5,237,532	2,890,666	5,323,643	4,462,251	247,559	218.9	3,479,822	775,281	2,487,285	103.4		60,436	2.7		95,386
Montana	4,463,849	2,714,208	6,944,034	4,305,635	2,060,410	622.3	729,270	111,796	617,474	30.8	33,476	6,374	7.3	12,942	29,949
Nebraska	3,914,481	1,982,182	5,774,256	3,867,871	795,629	428.7	1,444,942	18,006	1,175,618	50.4				28,604	10,934
Nevada	2,909,387	1,350,356	3,841,442	2,758,996	1,001,569	399.0	523,181	127,315	334,320	83.9		2,850		23,075	11,617
New Hampshire	692,119	465,404	1,181,047	692,119	440,896	23.3									24,508
New Jersey	3,173,019	951,379	3,092,894	2,793,057	109,956	46.7	933,099	345,862	490,464	5.9		160,316	7.5	34,100	190,643
New Mexico	2,846,648	1,676,769	4,241,639	2,711,206	1,375,407	408.9	349,999	62,413	287,586	22.7	37,087			35,941	13,777
New York	10,234,915	3,673,231	13,475,251	9,641,772	1,057,480	248.2	5,533,630	576,975	2,440,202	104.4	12,000	1,000	.2	4,168	174,549
North Carolina	4,761,147	1,930,365	5,932,907	4,069,839	727,112	720.4	1,179,344	349,255	780,496	80.4	64,450	350,113	8.8	277,603	72,644
North Dakota	2,902,224	1,469,483	3,972,735	2,721,258	641,515	1,345.9	187,085	54,799	67,755	42.2	46,291	275,180	38.5	79,875	485,035
Ohio	7,277,758	3,539,256	9,302,754	7,123,972	1,581,609	241.4	1,736,287	136,761	1,468,057	27.0	1,500	322,726	5.3	15,525	166,863
Oklahoma	4,608,399	2,342,590	5,580,299	4,262,946	1,151,757	357.1	1,501,714	339,781	1,020,413	45.3		93,545	6.8	5,672	76,875
Oregon	3,053,448	1,426,910	4,152,473	2,905,698	812,953	224.5	768,746	102,555	574,540	24.7				45,195	39,417
Pennsylvania	6,641,194	4,554,082	10,513,249	6,488,594	3,629,165	203.9	994,231	136,292	827,482	20.2	2,126	97,435	.2	14,182	
Rhode Island	988,230	474,772	1,528,596	988,230	464,572	34.9	3,800		3,800						6,400
South Carolina	2,729,583	940,954	2,917,808	2,601,428	249,246	250.7	517,305	72,536	444,769	27.0	11,220	72,537	.5	44,399	174,402
South Dakota	3,005,739	1,523,822	4,392,586	2,717,329	1,136,690	737.6	481,902	287,327	194,575	80.7		108,915	15.9	1,083	83,641
Tennessee	4,246,309	2,105,453	5,786,328	4,105,518	982,164	222.6	994,654	70,497	827,756	32.4	11,254	183,445	2.0	59,040	112,088
Texas	11,588,643	6,858,253	15,189,673	11,436,596	3,078,680	1,321.3	3,651,524	147,758	3,299,383	233.0		432,897	8.9	4,288	47,293
Utah	2,367,205	1,066,345	3,232,606	2,322,418	634,740	284.7	409,671	37,000	277,450	18.3		117,000	1.5	7,787	37,155
Vermont	928,184	466,042	1,365,864	912,376	344,959	64.2	128,565		114,302	3.1	3,922	2,713		11,887	4,068
Virginia	3,731,207	1,916,178	5,334,896	3,495,658	1,363,583	228.1	682,226	170,553	443,015	33.0	31,855	36,343	7.2	33,141	73,237
Washington	3,057,934	1,553,206	3,453,175	2,859,191	567,860	117.2	1,285,755	198,743	960,335	13.2		6,678			18,333
West Virginia	2,013,405	1,140,167	2,468,769	1,946,307	469,952	90.5	446,018	41,447	401,067	15.1	6,984	3,000	.1	18,668	266,147
Wisconsin	4,697,518	1,818,970	6,090,771	4,660,540	1,166,047	275.7	716,056	25,000	587,928	33.5	7,300	58,559	.4	4,678	6,437
Wyoming	2,250,663	1,686,368	3,426,209	2,105,140	1,156,834	656.4	654,160	141,021	486,981	78.1		37,872		4,502	4,681
District of Columbia															
Hawaii	1,693,344	598,778	1,326,739	952,902		27.3	1,124,830	681,972	283,004	13.4	20,973	10,000	.3	37,497	305,774
TOTALS	184,963,342	93,641,394	244,566,525	172,800,412	44,365,621	15,755.5	57,187,788	10,269,289	40,421,552	2,227.4	364,558	3,639,589	139.0	1,529,083	5,214,632

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF SEPTEMBER 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 2,384,804	$ 2,063,925	$ 300,204	61.5	$ 445,135	$ 282,675	$ 162,460	13.6	$ 11,886	$ 201,702	3.7	$ 31,441	$ 400,594
Arizona	756,982	289,673	743,863	622,804	86,475	15.1	327,960	129,321	161,999	.4				4,857	41,199
Arkansas	1,964,534	857,025	2,207,912	1,733,378	371,635	52.3	471,808	100,471	370,685	9.9	116,801	65,733	1.4	13,883	48,972
California	4,213,986	2,219,360	5,537,987	3,857,146	956,332	71.9	2,900,148	356,840	1,087,744	8.6		61,500	.7		113,784
Colorado	1,718,633	190,000	1,937,326	1,670,277	170,641	40.0	11,229	11,229		.8				37,127	19,359
Connecticut	802,407	426,500	838,564	802,407	9,362	10.3	193,692		142,521	1.6		261,170	1.8		13,447
Delaware	460,409	230,849	560,829	460,282	92,040	9.2						42,012		127	96,797
Florida	1,459,649	501,200	1,885,653	1,441,744	146,700	21.8	299,430		259,531	3.3		9,922		17,905	85,047
Georgia	2,724,620	1,278,373	2,437,627	2,229,933	170,446	76.8	671,956	266,401	382,267	16.1		31,607	1.2	228,285	694,053
Idaho	1,197,829	321,126	1,225,345	1,150,878	28,989	21.3	290,885		257,428	3.0				46,951	34,709
Illinois	7,381,910	2,230,350	6,623,661	6,283,943	8,850	66.3	2,706,002	1,083,605	1,622,397	14.8		102,041	1.5	14,362	497,062
Indiana	4,287,050	2,248,858	4,118,138	3,627,832	315,172	77.7	2,186,194	601,075	1,584,942	26.8	558	138,072	1.6	57,586	210,572
Iowa	2,614,472	1,280,000	3,216,653	2,443,068	631,635	76.4	614,808	171,365	403,200	5.8				39	245,165
Kansas	2,522,401	1,432,949	3,136,698	2,473,483	509,645	48.3	927,627		912,325	8.8	48,918	10,980	1.2		
Kentucky	1,927,828	958,599	1,959,805	1,579,834	306,055	40.2	713,670	316,559	377,205	7.9		102,091	1.7	31,435	173,248
Louisiana	1,708,577	744,560	975,918	792,968	172,967	24.0	1,229,217	896,730	290,445	15.0	10,666	218,453	2.2	8,212	62,694
Maine	960,426	484,379	1,060,684	910,266	144,844	19.4	378,629	45,122	319,605	3.8				5,038	19,930
Maryland	891,132	452,514	434,293	422,624		3.8	1,279,775	460,911		2.2				7,597	452,514
Massachusetts	5,007,199	847,600	3,236,487	3,004,220	157,851	18.5	2,092,009	1,974,333	117,676	1.4		464,671	.1	28,646	107,402
Michigan	3,500,637	1,613,142	4,014,733	3,322,717	501,900	48.3	1,166,700	155,650	998,550	11.4		91,200	.7	22,271	21,492
Minnesota	3,719,143	1,421,494	3,724,614	3,118,591	533,952	121.6	1,067,111	514,701	456,767	11.8	2,310	50,385	.6	83,541	380,391
Mississippi	1,744,669	354,022	1,346,607	1,192,935	132,313	42.9	690,415	509,356	110,023	18.6		12,352	1.1	42,378	99,335
Missouri	4,019,501	919,152	3,330,569	3,175,479	53,094	56.8	1,174,210	692,890	455,539	10.7		410,520	.9	151,132	
Montana	1,115,962	113,092	1,155,934	1,047,354	66,149	41.0	41,853	35,859	5,994	2.6				32,750	40,949
Nebraska	1,957,240	991,091	2,572,043	1,915,583	618,581	46.5	296,930	25,623	271,307	4.8	16,035		.4		101,203
Nevada	500,051	100,000	539,499	473,788	56,234	10.8	67,552	26,150	41,402	.6				113	2,364
New Hampshire	740,334	242,465	853,411	668,379	181,465	19.0	46,123		46,123	.3	22,006		.4	49,949	14,877
New Jersey	3,117,921	1,809,500	3,247,132	2,983,109	117,435	23.1	1,178,660	10,297	929,815	5.7		626,855	1.0	124,515	135,394
New Mexico	1,674,158	529,506	1,824,716	1,560,253	249,529	41.9	183,963		183,963	1.1				113,905	96,014
New York	8,092,500	3,961,690	9,127,508	7,835,941	717,700	69.8	3,099,630	250,500	2,793,440	16.6		57,000		6,059	393,550
North Carolina	2,380,573	1,210,236	3,228,526	2,235,534	953,794	105.3	300,711	120,471	180,240	6.9		42,413	.5	24,568	33,789
North Dakota	1,451,112	734,742	1,496,382	1,302,987	184,645	64.2	206,717	96,271	110,446	10.0	51,854	138,959	8.3		300,691
Ohio	4,335,686	2,359,503	5,422,788	4,237,739	677,374	71.7	1,499,530	93,352	1,284,740	11.7		347,700	1.5	4,595	49,689
Oklahoma	2,304,200	1,171,295	2,761,523	2,262,279	401,011	53.4	606,689	39,634	551,372	6.7		96,583	.9	2,288	122,328
Oregon	1,526,724	778,728	2,085,475	1,482,265	541,885	40.1	270,997		234,525	2.2	518			43,921	2,318
Pennsylvania	4,837,988	2,397,703	6,557,054	4,791,003	1,467,935	84.5	291,409		290,470	.9	40,000	244,787	1.8	6,985	394,510
Rhode Island	512,665	285,760	650,675	508,370	140,964	8.9								4,295	144,796
South Carolina	1,364,791	488,000	1,298,762	1,233,572	53,000	40.6	345,969	124,414	216,005	10.8	6,805	15,412	.1		203,584
South Dakota	1,502,870	761,910	1,385,834	1,243,836	141,263	43.2	360,408	65,622	294,786	21.3	6,853	62,305	3.8	186,559	262,957
Tennessee	2,123,155	1,121,790	2,462,842	2,054,124	322,219	31.7	654,103	69,031	585,072	4.8		58,746	.6		155,753
Texas	6,642,863	1,795,000	6,309,642	5,722,509	454,734	142.3	1,659,538	666,033	813,546	19.4	2,192	485,881	5.8	252,129	40,839
Utah	778,826	533,173	1,122,592	649,146	364,373	27.8	333,602	129,130	167,800	6.5		1,000		550	
Vermont	500,509	240,611	730,862	486,227	161,761	17.2	66,356		66,296	1.5		8,129	.4	14,282	4,425
Virginia	1,948,780	956,021	2,519,547	1,704,936	565,758	39.3	547,137	220,395	276,424	7.8	9,099	69,057	2.5	14,349	44,781
Washington	1,977,260	776,603	2,564,806	1,974,755	568,864	45.9	175,618		175,618	1.6		1,415		2,505	30,706
West Virginia	1,342,270	574,085	1,178,195	1,112,989	28,109	18.6	590,094	229,220	331,388	8.6		110,272	.1	61	104,316
Wisconsin	2,596,143	1,374,513	3,727,717	2,509,104	1,140,176	70.6	241,862	53,457	183,352	3.6		55,985	1.2	33,582	
Wyoming	1,125,332	29,416	1,104,126	1,098,148	2,784	23.5	36,783	22,068	14,132	2.5		10,284		5,116	2,216
District of Columbia	946,445	181,051	1,127,496	946,445	181,051	6.6									
Hawaii															
TOTALS	115,370,280	47,885,170	123,993,857	102,421,129	16,159,895	2,211.9	34,940,844	10,846,761	20,521,565	354.8	346,501	4,707,794	49.7	1,755,889	6,495,916

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF SEPTEMBER 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,032,452	$1,064,960	$2,430,557	$1,921,746	$486,536	169.3	$576,844	$61,735	$515,109	31.6		$63,180	2.7	$48,971	$135
Arizona	599,423	971,211	1,139,094	530,962	554,239	99.4	423,540	59,762	363,778	34.9				8,699	53,194
Arkansas	1,449,674	857,024	1,599,763	1,337,792	249,811	137.4	649,483	79,018	568,398	72.4		31,680	3.1	32,864	7,135
California	3,450,440	1,999,203	[illegible]	3,250,107	718,369	[illegible]	[illegible]	196,170	1,147,259	36.6				4,163	133,575
Colorado	1,718,632	871,502	2,682,390	1,608,432	623,474	176.9	478,158	110,200	248,028	34.8					
Connecticut	669,120	420,868	920,180	669,120	235,769	19.5						125,141	1.9		59,958
Delaware	481,113	230,849	509,649	277,564	230,280	68.8	203,723	203,549		2.5					569
Florida	1,302,816	1,047,643	1,692,424	1,276,273	344,194	83.3	664,116		612,569	42.1		15,856		26,543	25,321
Georgia	2,320,973	1,278,373	2,027,502	1,842,659	146,570	149.4	776,023	385,910	390,113	50.5				92,404	741,690
Idaho	1,121,662	824,450	1,828,824	1,094,630	611,868	217.5	136,457		136,457	6.7				27,032	76,125
Illinois	5,780,033	4,292,273	6,167,139	5,051,596	1,064,616	[illegible]	3,518,425	715,339	2,803,086	173.1		104,975	2.7	13,098	319,596
Indiana	731,672	151,473	531,668	466,033	16,004	56.6	321,965	227,343	94,129	43.3				38,296	41,340
Iowa	2,413,358	1,875,000	3,476,969	2,392,379	982,745	464.3	921,993	20,027	854,300	139.4		[illegible]	2.3	952	[illegible]
Kansas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
Kentucky	1,837,866	1,047,503	2,538,453	1,813,920	578,415	363.1	974,615		408,100	166.1		55,506	3.0	23,946	5,482
Louisiana	1,426,879	838,953	1,275,331	1,085,063	177,832	54.1	908,081	337,378	570,724	42.0	$3,135	74,211	2.5	1,303	16,186
Maine	842,479	445,012	1,393,836	842,403	429,831	105.7	13,424		13,424	.8				75	1,757
Maryland	891,132	1,024,708	1,218,325	876,320	283,690	79.8	209,560		209,560	6.9	9,800	196,094	6.3	5,012	335,364
Massachusetts	488,185	920,000	482,233	474,504		15.2	837,333		837,333	20.4				13,681	82,667
Michigan	3,184,057	1,713,142	3,556,903	3,025,292	278,850	222.2	1,462,552	117,227	1,344,325	78.0		84,300	3.3	41,538	5,667
Minnesota	2,376,415	1,470,324	3,619,283	2,178,974	1,183,512	399.9	382,150	133,322	227,827	16.3		37,523	.1	64,119	21,462
Mississippi	1,744,669	354,023	1,383,690	1,367,190	16,500	150.3	456,153	349,342	106,811	36.4		197,261	17.9	28,137	33,451
Missouri	2,923,273	2,363,922	3,841,407	2,828,144	926,260	816.4	1,418,891	93,414	1,279,720	230.7		157,941	10.7	1,716	
Montana	1,859,937	942,434	2,585,856	1,739,224	836,801	310.8	166,200	68,565	97,635	16.1				52,149	7,998
Nebraska	1,957,240	991,091	2,598,664	1,953,891	621,814	449.3	358,629		314,125	51.9		55,152	2.8	3,349	
Nevada	1,136,479	852,000	1,737,865	1,109,579	578,758	211.9	240,641	8,443	232,198	24.7				18,457	41,043
New Hampshire	477,386	261,593	754,680	475,526	229,412	33.4	22,102		20,000	.8				1,860	12,181
New Jersey	55,099	460,000	56,528	55,099		.5	107,525		107,525	1.7		213,355	1.1		139,121
New Mexico	1,272,129	735,425	1,920,315	1,272,129	646,136	295.1	73,332		73,332	2.6					15,956
New York	4,002,686	3,693,000	5,963,461	3,538,046	1,616,289	217.0	2,622,520	327,200	1,996,050	166.9				137,440	80,661
North Carolina	2,380,573	1,700,340	3,131,693	2,246,077	880,817	346.9	908,856	90,285	818,571	82.7	44,161		.9	50	952
North Dakota	1,451,112	734,742	1,437,412	1,293,948	142,627	444.2	317,008	95,421	221,587	76.4	31,234	262,180	64.2	30,508	108,348
Ohio	3,871,148	1,966,253	4,637,208	3,762,196	622,944	361.2	1,034,673	37,360	943,929	53.9	47,700	168,740	13.3	23,892	210,640
Oklahoma	2,304,199	1,171,295	2,560,728	2,154,542	146,861	290.4	1,075,747	147,071	849,239	43.3		29,343	.3	2,586	145,852
Oregon	1,526,724	892,176	2,470,262	1,494,881	771,691	172.3	59,551	19,526	4,700	1.6				12,317	115,785
Pennsylvania	7,411,822	2,639,003	8,180,744	6,578,394	1,342,592	628.7	2,035,033	669,709	1,272,269	126.2		15,701		163,719	8,441
Rhode Island	497,813	254,040	497,631	447,809	39,789	34.2	211,374		211,374	7.1	50,004		3.0		2,876
South Carolina	1,364,791	1,342,000	1,328,650	1,089,302	233,769	136.9	1,318,840	249,891	1,030,599	156.3		70,760	3.6	25,598	6,872
South Dakota	1,502,870	761,911	1,873,256	1,424,764	443,659	536.1	255,492	69,046	186,446	75.8		119,584	28.0	9,060	12,222
Tennessee	2,123,155	1,075,748	2,409,369	1,951,410	366,515	165.0	510,131	103,127	407,004	22.0	3,663	138,374	3.2	64,955	163,855
Texas	6,012,518	3,638,000	8,067,322	5,987,309	1,588,118	942.8	2,040,331		2,040,331	104.2		1,000	14.2	25,209	8,551
Utah	1,048,677	533,173	1,730,899	1,040,016	393,173	236.1	166,380		140,000	16.0				8,661	
Vermont	438,880	241,354	811,648	435,360	240,452	53.2								3,520	903
Virginia	1,736,770	893,188	2,007,451	1,565,227	383,311	240.8	452,637	129,548	313,003	45.1	17,600	148,154	14.9	24,396	48,721
Washington	1,080,673	776,603	1,672,985	1,080,673	550,517	117.8	226,087		226,087	7.1					
West Virginia	1,118,559	570,083	951,249	856,050	50,375	46.8	601,424	257,170	344,254	31.9		103,572	6.7	5,338	71,883
Wisconsin	2,431,220	1,743,354	3,451,065	2,341,749	844,852	205.9	957,325	68,000	779,377	30.9		117,484	.2	21,471	1,641
Wyoming	1,125,332	571,928	1,443,025	1,122,741	302,796	242.1	269,134		269,132	35.1				2,590	
District of Columbia	972,024	792,791	1,449,096	971,729	477,367	12.2	104,932		104,932	.7		75,395	.6	296	135,097
Hawaii	177,718	351,000	178,209	177,718		4.9	150,713		143,867	4.6					207,133
TOTALS	93,666,378	58,473,436	117,931,573	86,921,821	24,813,047	11,574.8	34,082,849	5,426,590	27,381,559	2,448.6	207,297	2,718,058	213.1	1,110,670	3,560,772

PUBLICATIONS *of the* BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

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DEPARTMENT BULLETINS

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No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

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Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

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Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF SEPTEMBER 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 12,045,614	$ 7,645,675	$ 1,256,493	625.7	$ 2,712,573	$ 632,159	$ 1,905,046	130.1	$ 11,886	$ 282,827	5.9	$ 80,412	$ 815,476
Arizona	5,211,960	2,641,935	7,155,606	4,983,510	1,322,254	496.1	1,550,978	204,122	1,201,829	48.7				24,328	117,852
Arkansas	6,748,335	3,428,049	7,955,007	5,874,055	1,261,875	435.6	2,636,987	672,287	1,674,462	163.3	116,301	129,603	4.7	85,192	162,108
California	15,607,354	7,932,206	22,345,528	14,927,594	2,715,166	677.2	7,587,623	674,238	4,760,303	97.1		72,703	1.2	5,522	383,534
Colorado	6,874,530	3,486,006	10,499,653	6,638,521	3,080,740	602.1	702,954	193,882	376,836	43.3				37,127	28,431
Connecticut	2,865,740	1,454,868	3,351,652	2,859,541	245,131	60.5	864,638		697,247	8.3		386,311	3.7	6,199	126,179
Delaware	1,819,088	923,395	2,445,348	1,615,412	778,920	126.8	204,835	203,549	1,102	2.5		42,012		127	101,361
Florida	5,231,334	2,661,343	7,471,014	5,091,671	1,228,636	252.2	1,270,761	59,479	1,092,579	54.5		210,675	2.2	80,684	129,453
Georgia	10,091,185	5,113,491	10,146,219	8,424,100	1,395,409	603.8	2,727,468	1,138,282	1,432,874	117.5	5,136	51,025	1.6	473,666	2,234,133
Idaho	4,486,249	2,277,486	5,937,410	4,404,280	1,204,767	470.4	781,333		737,223	20.1		1,570	.1	81,370	[illegible]
Illinois	17,570,770	8,921,401	16,386,565	14,333,710	1,554,126	451.0	9,277,279	3,135,234	6,141,179	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
Indiana	10,077,843	5,083,903	9,221,733	8,443,334	435,324	263.5	5,640,452	1,416,271	4,170,514	222.5	557	[illegible]	[illegible]	[illegible]	[illegible]
Iowa	10,066,660	5,116,361	13,368,202	9,822,077	1,311,917	1,062.6	1,355,801	232,592	1,521,940	162.7		25,600	[illegible]	931	[illegible]
Kansas	10,089,504	5,117,675	12,136,711	9,461,125	1,841,020	374.0	3,349,734	70,683	3,241,251	160.1	48,918	35,405	2.2	8,878	
Kentucky	7,517,359	3,818,311	8,724,794	6,906,083	1,335,632	650.3	2,723,785	499,535	2,008,753	153.2	8,570	172,596	13.6	103,171	301,330
Louisiana	5,828,591	2,963,932	5,344,257	4,359,891	444,446	157.5	3,225,797	1,268,371	1,903,235	83.2	54,022	316,069	5.8	146,308	295,132
Maine	3,369,917	1,711,586	4,617,774	3,296,917	1,163,572	182.6	539,535	50,301	525,318	11.4				22,699	22,696
Maryland	3,564,527	1,810,058	2,874,905	2,396,193	407,217	105.4	2,213,807	1,055,712	339,230	25.3	9,800	224,652	7.7	102,822	838,959
Massachusetts	6,597,100	3,350,474	5,793,833	4,527,690	688,157	81.7	3,505,333	2,027,020	1,473,313	31.5		964,057	2.2	42,389	219,947
Michigan	12,736,227	6,452,568	14,832,357	12,286,502	1,735,850	562.8	4,885,152	381,677	4,445,212	199.0		244,348	7.1	68,048	27,159
Minnesota	10,656,569	5,425,551	14,365,154	9,758,623	4,007,490	1,587.8	1,767,147	741,696	864,714	60.5	2,310	90,982	.6	153,940	462,364
Mississippi	6,978,675	3,540,227	8,835,141	5,413,555	986,496	515.1	3,645,641	1,415,362	1,772,878	188.2	20,193	273,907	23.1	129,565	506,946
Missouri	12,180,306	6,173,740	12,495,619	10,465,874	1,226,912	1,092.2	6,072,923	1,561,585	4,222,545	344.8		628,897	14.2	152,348	95,366
Montana	7,439,748	3,769,734	10,685,824	7,092,213	2,963,360	974.1	937,323	216,219	721,104	49.5	33,476	6,374	7.3	97,340	78,896
Nebraska	7,828,961	3,964,364	10,944,963	7,737,345	2,036,024	924.5	2,100,502	43,628	1,761,050	107.0	16,035	55,152	3.2	31,953	112,137
Nevada	4,545,917	2,302,356	6,118,807	4,342,364	1,636,561	621.7	831,374	161,908	607,920	109.1		2,850		41,645	55,025
New Hampshire	1,909,839	969,462	2,789,138	1,836,024	851,772	75.7	68,226		66,123	1.0	22,006		.4	51,809	51,566
New Jersey	6,346,039	3,220,879	6,396,554	5,831,264	227,391	70.3	2,219,284	356,159	1,527,804	13.2		1,000,526	9.6	158,615	465,158
New Mexico	5,792,935	2,941,700	7,986,670	5,543,588	2,271,072	745.9	607,295	62,414	544,881	26.5	37,087			149,846	125,747
New York	22,330,101	11,327,921	28,566,220	21,015,760	3,391,469	535.0	11,255,780	1,154,675	7,229,692	287.9	12,000	58,000	.2	147,666	646,761
North Carolina	9,522,293	4,840,941	12,293,127	8,551,450	2,561,723	1,172.6	2,388,911	560,011	1,779,307	169.9	108,611	392,526	10.2	302,221	107,385
North Dakota	5,804,448	2,938,967	6,906,529	5,318,194	968,787	1,854.3	710,810	246,491	399,788	128.7	129,380	676,319	111.0	110,383	894,074
Ohio	15,484,592	7,865,012	19,362,750	15,123,908	2,881,927	674.4	4,270,490	267,473	3,696,727	92.6	49,200	859,166	20.1	44,012	427,192
Oklahoma	9,216,798	4,685,180	10,902,549	8,679,766	1,699,630	700.8	3,134,150	526,486	2,421,024	95.4		219,471	8.1	10,546	345,055
Oregon	6,106,896	3,097,814	8,708,211	5,882,864	2,126,528	437.0	1,099,294	122,081	813,765	28.5	518			101,434	157,521
Pennsylvania	18,891,004	9,590,788	25,351,047	17,857,990	6,439,693	917.0	3,320,673	806,002	2,390,221	147.3	42,126	357,923	2.0	184,886	402,951
Rhode Island	1,998,708	1,014,572	2,676,902	1,944,409	645,325	78.0	215,174		215,174	7.1	50,004		3.0	4,295	154,072
South Carolina	5,459,165	2,770,954	5,545,219	4,924,302	536,015	428.2	2,182,114	446,841	1,691,372	194.1	18,025	158,709	4.2	69,998	384,857
South Dakota	6,011,479	3,047,643	7,651,676	5,385,928	1,721,612	1,316.8	1,097,802	421,994	675,808	177.8	6,853	291,404	47.7	196,703	358,820
Tennessee	8,492,619	4,302,991	10,658,539	8,111,052	1,670,897	419.3	2,158,888	242,654	1,819,832	59.2	14,917	380,566	5.8	123,995	431,696
Texas	24,244,024	12,291,253	29,566,638	23,146,414	5,121,532	2,406.4	7,351,392	813,792	6,153,261	356.7	2,192	919,778	28.8	281,626	96,683
Utah	4,194,708	2,132,691	6,086,097	4,011,580	1,392,286	548.6	909,653	166,130	585,250	40.9		118,000	1.5	16,998	37,155
Vermont	1,867,573	948,007	2,908,374	1,833,963	747,172	134.5	194,921		180,597	4.6	3,922	10,842	.4	29,688	9,396
Virginia	7,416,757	3,765,387	9,861,894	6,765,821	2,312,652	508.2	1,682,000	520,496	1,032,442	85.9	58,554	253,554	24.6	71,886	166,739
Washington	6,115,867	3,106,412	7,690,965	5,914,619	1,687,241	280.9	1,687,460	198,743	1,362,039	21.9		8,093		2,505	49,038
West Virginia	4,474,234	2,280,335	4,598,213	3,915,346	548,436	156.0	1,637,535	527,838	1,076,709	55.6	6,984	216,843	6.9	24,066	438,347
Wisconsin	9,724,881	4,941,837	13,269,553	9,511,393	3,151,075	552.1	1,915,243	146,457	1,550,656	68.0	7,300	232,028	1.9	59,732	8,078
Wyoming	4,501,327	2,287,712	5,973,360	4,326,029	1,462,414	922.0	960,076	163,089	770,245	115.7		48,156		12,208	6,898
District of Columbia	1,918,469	973,842	2,576,592	1,918,173	658,419	18.8	104,932		104,932	.7		75,395	.6	295	135,097
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,275,543	681,972	426,870	18.0	20,973	10,000	.3	37,497	512,908
TOTALS	394,000,000	200,000,000	486,491,955	362,143,362	85,338,563	29,542.2	126,211,481	26,542,640	88,324,676	5,030.8	918,356	11,065,441	401.8	4,395,642	15,271,320

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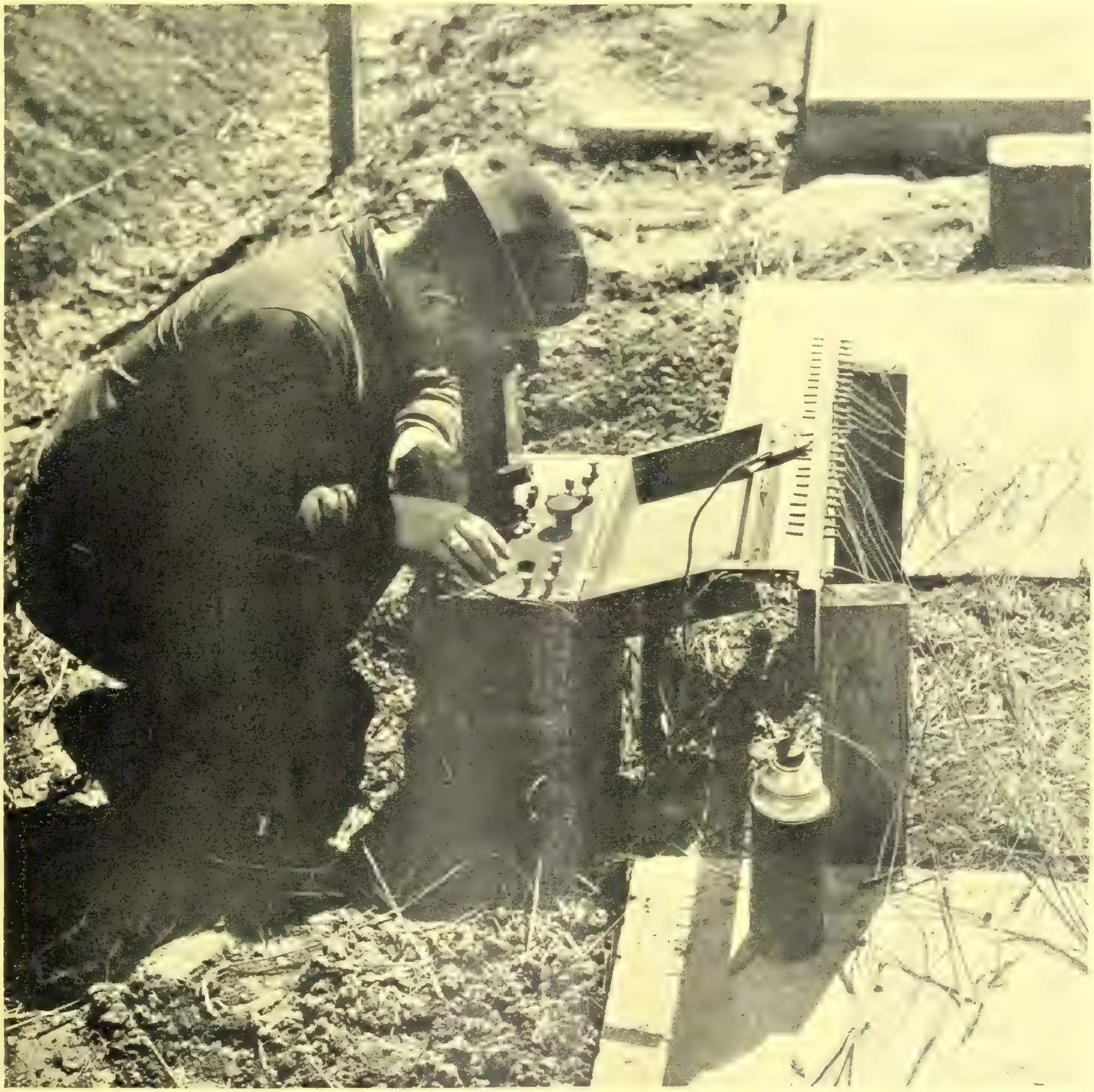

DETERMINING PAVEMENT TEMPERATURE USING EMBEDDED THERMOCOUPLES

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PUBLIC ROADS

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BUREAU OF PUBLIC ROADS

Volume 16, No. 9 November 1935

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **L. W. TELLER**, Senior Engineer of Tests, and **EARL C. SUTHERLAND**, Associate Highway Engineer

PART 2.—OBSERVED EFFECTS OF VARIATIONS IN TEMPERATURE AND MOISTURE ON THE SIZE, SHAPE, AND STRESS RESISTANCE OF CONCRETE PAVEMENT SLABS

IT HAS been known for more than half a century that when the temperature or the moisture content of portland cement concrete is changed a corresponding change in volume occurs. Since the pioneer work of Bauschinger [1] in this field many other research workers have contributed to the store of information concerning the extent of these changes and the factors that affect them.

As concrete began to be generally used as a paving material engineers gradually came to appreciate that, under some conditions at least, these volume changes were of such magnitude that provision for them was necessary in the pavement design.

Because of the relative physical proportions of a pavement slab, it was but natural that the first manifestation of volume change to be noticed was expansion and contraction in a longitudinal direction. More than 20 years ago the Bureau studied the expansion and contraction of concrete pavements [2] in an effort to discover the laws that govern such movements.

RESULTS OF EARLY INVESTIGATIONS INADEQUATE FOR PAVEMENT DESIGN

The early investigations were of value, first, for the information that they developed, and, second, because each one served to arouse more wide-spread interest in the subject among highway engineers. As a result of this interest new researches were begun and it was soon discovered that differences in temperature between the upper and lower surfaces of a pavement slab would cause it to warp to a measurable degree,[3] and further, that a similar warping could be brought about by creating a moisture differential between the two surfaces of a concrete slab.[4]

These discoveries were important because the exposure conditions to which pavements are subjected are severe; and expansion, contraction, and warping may be expected daily throughout the life of a concrete pavement slab. If the slab were completely free to move and had no weight it would change in size and shape without restraint and no stress would result. Because of its weight and intimate contact with the subgrade, however, restraint in some degree is always present and every attempt of the slab to change either its size or shape develops stress within the structure.

Other early tests indicated the approximate amount of resistance encountered when the pavement slab expands or contracts longitudinally along the subgrade,[5] and the development of this information made it possible to estimate approximately the tensile or compressive stresses induced in the concrete by this form of restraint.[6]

More recently a careful analysis has been made of the theoretical stress conditions resulting from slab warping caused by temperature differences within the concrete and assumed conditions of restraint.[7] This analysis supplies the means for estimating the stresses that occur under certain conditions of temperature warping.

EXTENSIVE PROGRAM OF STUDY OF MOISTURE AND TEMPERATURE EFFECTS UNDERTAKEN

It will be noted that each of the researches referred to has contributed some information that represents a distinct step toward a better understanding of the reasons for observed slab behavior. However, the engineer who undertakes to apply the information obtained by these previous studies to the design of a pavement finds that there are numerous gaps and uncertainties in the data. When the pavement-design project at Arlington was being planned, it was decided to include a study of the extent of the moisture and temperature changes that occur in pavements in this locality and to determine, as fully as possible, the effect of those changes on the pavement slab. The rather extensive program of observations outlined in part 1 of this series was developed with this object in mind.

The observations that have been made may be grouped according to purpose as follows:

1. A study of the extent of the temperature changes that occur in the various parts of concrete pavement slabs.
2. A study of the longitudinal expansion and contraction of pavement slabs caused by temperature changes and changes in moisture content.
3. A study of the resistance offered by the subgrade to horizontal slab displacement and of the stresses developed in the slab by this resistance.
4. A study of the warping of concrete pavement slabs resulting from variations in temperature and of the stress conditions that result from warping.

The tests and observations reported in this paper were made on the 10 full-size pavement slabs and, in general, the data cover periods of time of from 1 to 3 years. The complete description of the test sections and of the methods of test employed has already been given in part 1 of this series.[8]

---

[1] Tests of Different Portland Cements, by J. Bauschinger, Mitt. Mech. Tech. Lab., Tech. Hochschule (Munich) v. 8, 1879.

[2] The Expansion and Contraction of Concrete and Concrete Roads, by A. T. Goldbeck and F. H. Jackson, Bull. 532, U. S. Department of Agriculture, October 1917.

[3] The Bates Experimental Road, by Clifford Older, and Highway Researches and What the Results Indicate, by A. T. Goldbeck, papers in the Proc. American Road Builders' Association, 1922.

[4] Effect of Moisture on Concrete, by W. K. Hatt, PUBLIC ROADS, vol. 6, no. 1, March 1925.

[5] Friction Tests of Concrete on Various Subbases, by A. T. Goldbeck, PUBLIC ROADS, vol. 5, no. 5, July 1924.

[6] The Interrelationship of Longitudinal Steel and Transverse Cracks in Concrete Pavements, by A. T. Goldbeck. PUBLIC ROADS, vol. 6, no 6, August 1925.

[7] Analysis of Stresses in Concrete Roads Caused by Variations in Temperature, by H. M. Westergaard. PUBLIC ROADS, vol. 8. no. 3, May 1927.

[8] The Structural Design of Concrete Pavements, Part 1, by L. W. Teller and Earl C. Sutherland, PUBLIC ROADS, vol. 16, no. 8, October 1935.

25615—35——1

TEST PROCEDURE DESCRIBED

Temperature measurements.—The temperature measurements were made in large part on two small slabs that were constructed especially for this purpose some months after the 10 test sections were constructed. These slabs, shown on the cover page, are 4 feet square, one being 6 and the other 9 inches in thickness. They were constructed on the subgrade adjacent to the test sections and the materials and proportions used in the concrete were exactly the same as were used for the large slabs.

The resistance thermometers originally installed in the large slabs were not entirely satisfactory for several reasons, so when the slabs for temperature measurements were built copper-constantan thermocouples were installed. The thermocouples were located at the centers of the slab areas and at 1-inch intervals throughout the depth, and also at both upper and lower slab surfaces. Two thermocouples were also placed in the subgrade beneath each slab, one about one-fourth inch and the other about 2 inches below the surface of the subgrade.

With these installations it was possible to determine quite completely the temperature conditions that existed throughout the depth of the slab. From these data one may estimate with considerable accuracy both the average temperature of the slab and the temperature differential between its upper and lower surfaces. In estimating the temperature conditions for the various pavement sections from the data obtained from the thermocouples, two assumptions were made: First, that the temperatures in the pavement slab were the same as those found in the slab of equal thickness on which temperature measurements were made; and second, that the temperature of slabs having thicknesses intermediate between 6 and 9 inches could be predicted by a straight-line interpolation between the temperatures measured in the 6- and 9-inch slabs.

The average temperature of the slab was obtained by averaging the temperatures measured at the several points throughout its depth. The temperature differential was estimated by drawing a mean curve for the data which were plotted to show the variation in temperature through the slab depth, and from this mean curve taking the indicated temperatures for the upper and lower surfaces of the pavement.

The temperature measurements were usually made in connection with measurements of slab expansion or of slab warping. They cover a period of approximately 2 years and, while not continuous, were planned so as to develop full information concerning both the daily and yearly temperature cycles that occurred during this time.

During the latter part of the investigation it became desirable to obtain data that would show the relation between the temperature differentials in thickened-edge cross sections and those in sections of constant depth. No means for obtaining these data were provided in the original construction and it was necessary to drill small holes to the proper points in the slab cross section, insert thermocouples in the bottom of these holes, and then backfill with cement-sand mortar. Thermocouples were placed in this manner near the upper and lower surfaces of the slab and at the third points of the slab depth, and this arrangement made it possible to estimate very closely the differential in temperature that existed at the several positions on the test sections at which the measurements were made.

Two types of information were desired: First, knowledge of how the temperature differential varie along the different types of cross section; and second a comparison of the differential in the edge of a 9-6- thickened-edge section with those which occur unde the same conditions in the edges of constant-thicknes sections of different depths. For the first purpose the thermocouple installations were made at distance of 2, 18, and 36 inches from the free edge, while for th second only the installation at 2 inches from the edg was used. In each case the thermocouple units wer placed at the various depths as described above.

Moisture measurements.—Since moisture variation within the concrete are known to cause physical change in the size and shape of the pavement slab that ar similar to those caused by temperature variations, i was desired to obtain quantitative data concerning th changes. Such data are difficult to obtain, however because there is no reliable method for determining th moisture content of concrete except by weighing an this is usually not feasible.

In this investigation the moisture content of th concrete was determined by weighing and dryin fragments broken from the short slabs originall provided for the purpose of furnishing samples. N means was found for determining differences in moistur content at various depths in the slabs so that no dat were obtained to show the nature of the moistur gradient at various seasons of the year. However measurements were made of the seasonal warpin presumably caused by such a moisture gradient Measurements were also made from which it was possible to determine the direct longitudinal expansion an contraction caused by factors other than temperatur change, and from these data it was found possible t estimate the extent and period of the yearly variatio in slab length attributable to moisture change alone.

The method of measuring the warping of the slab under the action of these seasonal moisture changes i described later.

Measurements of the expansion and contraction of th pavement sections.—Practically all of the slab-expansio data were obtained by measurements on the 6-inc constant-thickness section. This section was separate from the other nine by a space of several feet so tha there was no possibility of its being affected by th movements of the other slabs. Fixed reference point of the type shown in figure 1 were constructed at eac end of the 40-foot section, and the horizontal movemen of the slab ends with respect to these reference point was measured with the special micrometer describe in the previous paper. The movement at the transvers joint was measured at the same time. The frame of th micrometer is made of soft steel and its length change considerably with temperature changes. Correctio for this were made by referring all measurements to a invar standard, the length of which changes less tha 0.001 inch for a temperature change of 100° F.

The procedure followed was first to place the micron eter and reference bar out of doors and allow them t reach a condition of temperature stability. Th measurements at the slab ends were then made and ar change in the length of the micrometer, as indicated b the reference reading on the standard bar, applied as correction to the measured slab displacement.

The expansion and contraction measurements we made once or twice each month over a period of abo 4 years. Each set of observations was started in t early hours of the morning, before the minimum slab length was attained, and was continued until late in the evening, long after the maximum expansion had occurred. Measurements were made at 2-hour intervals during this time.

This daily cycle of observations and the related temperature data made possible the determination of the maximum and minimum slab lengths, the range in average slab temperatures that caused the length changes, and from these the length change per degree of temperature change for the slab as a whole.

The series of observations obtained over the yearly periods made possible the determination of not only the annual cycle of length change resulting from temperature but also those resulting from other causes, such as variation in moisture content.

In addition to the measurements at the ends of the 6-inch constant-thickness slab, some data were obtained from telemeters (resistance strain gages) that were installed at the center of one 10 by 20-foot panel in each of two other test sections at the time of construction. These instruments were placed in a longitudinal direction and in the neutral plane of the slab. They were in a position to receive direct longitudinal deformation but not deformation caused by bending of the slab. Each telemeter is provided with an electrical resistance thermometer housed within its shell with which the temperature within the telemeter can be measured at the same time that the deformations are determined.

The schedule of observations with the telemeters was the same as that followed in the measurement of the movement of the slab ends. The telemeter observations covered a period of about 2 years and coincided with the period of the micrometer measurements for only about 8 months, as shown later in figure 14. Failure of the resistance thermometer elements caused the abandonment of the telemeter observations.

Measurements of subgrade resistance to horizontal slab movement.—The measurement of the resistance offered by the subgrade to the horizontal displacement of the pavement slab was determined in tests made with small slabs cast upon the subgrade for this particular purpose, as described in part 1 of this series of papers. (See pt. 1, fig. 20.)

These slabs, each 4 feet square, were moved horizontally with a powerful, smoothly operating mechanical jack. The force required to cause the movement and the amount of the displacement were determined.

Before the tests were begun, a preliminary investigation was made to find a desirable test procedure. As a result of this preliminary work it was decided:

1. That the slabs should be moved at a very slow rate, one comparable with that which obtains in a pavement during the daily cycle of temperature variation.
2. That the slabs should be moved alternately in opposite directions.
3. That the magnitude of the displacement used in the tests should be comparable to the movements that occur at the ends of pavement slabs of moderate length under the influence of daily temperature variations.

This procedure subjected the subgrade under the mall test slabs to the same manipulation that it would eceive under the end of a pavement slab.

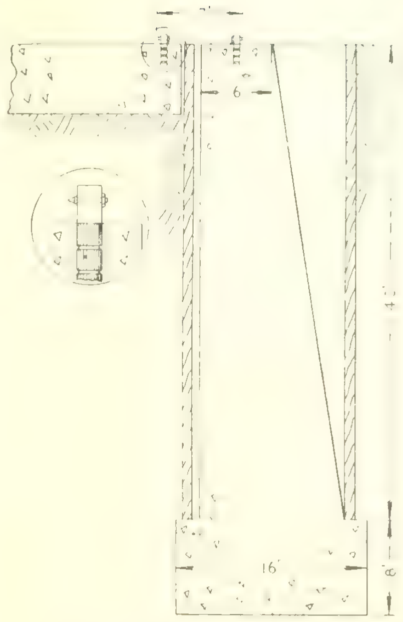

Figure 1.—Reference Point for Measuring Change in Length of Concrete Slab.

In a number of the tests the horizontal displacement f the subgrade at various depths was measured as the ab was displaced. In order to measure the movement of the subgrade, small recesses were cut into the earth just in front of the slab and micrometer dials were placed in these recesses. The dials were supported on a rigid member that was supported in turn by the subgrade at some distance from the slab. The stems of the dials bore against small wooden plugs inserted in the vertical face of the subgrade at the desired depths. The dials were usually placed at three points across the front or leading edge of the slab.

A few tests were made to determine the influence of slab thickness (or weight) on the resistance offered to horizontal displacement. For these tests four small slabs of 2-, 4-, 6-, and 8-inch thicknesses were constructed on the regular subgrade. The method followed in testing with these slabs was the same as that used with the 6-inch slabs previously described.

Warping measurements.—Observations have shown that under usual conditions of exposure there is seldom a time when the temperature of a pavement slab is uniform throughout. Either the air is warmer than the subgrade or vice versa, and heat is being conducted by the slab either to the subgrade or away from it. Because concrete is a relatively poor conductor of heat, the transfer of heat through a pavement of ordinary thickness takes time, and a differential in temperature is created within the various parts of the structure. Each element of the concrete attempts to adjust its volume to its own particular temperature.

As previously stated, if the slab were completely free and without weight it would assume a distorted shape without resistance and no stresses would result. Actually, almost no part of the slab is free to adjust itself and, while measurable distortion occurs, restraint caused by the slab weight and by the subgrade reactions is always present. It is apparent that the warping of a pavement is not a simple phenomenon and the distortion that is measured is the result of a very complex system of forces.

Warping has two important effects on the structural action of a pavement slab. In the first place, the distortion that occurs alters the condition of subgrade support and thus affects the magnitude of the stress that will be produced by a given wheel load. In the

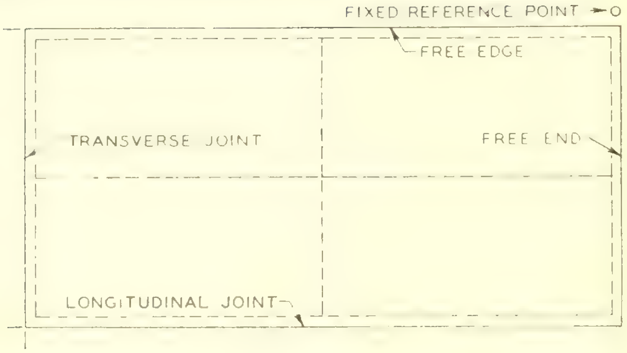

Figure 2.—Plan of 10- by 20-Foot Section Showing the Lines Along Which Deflections Were Measured.

second place, because of the weight of the slab, the warping in itself causes important stresses within the slab structure. Both of these actions place limitations on the maximum wheel load that may be carried by the pavement and, for this reason, any information concerning them is of value.

The studies of warping that were a part of this investigation were divided into three groups, as follows:

1. Measurement of the extent and characteristics of the actual warping that occurs in pavement slabs of conventional designs.
2. Determination of the magnitude of the effect of warping on the critical stresses caused by a given load applied at different points on the pavement slab.
3. Determination of the magnitude and distribution of the stresses caused by restraint to warping in the various parts of the pavement slab.

In order to determine the changes in shape that occur when the pavement warps, it is necessary to measure the vertical displacement of a great many points on its surface. In this investigation the measurements were confined to one quadrant or panel of the test section, and in this quadrant the shapes of the two principal axes and of all of the boundaries were determined. The lines along which the shape determinations were made are shown in figure 2. It will be noted that there is one free edge and one free end to the panel, and that the other edge and end are attached to the other panels of the test section by the longitudinal and transverse joints.

Clinometer points were set at 10-inch intervals along the lines shown in figure 2, and the shape of the slab was determined by measuring successively the slopes of these intervals with the 10-inch clinometer. The measurements were started from a bench mark or reference point located on the shoulder near the pavement, and were carried forward along the line of clinometer points exactly as a line of levels is run.

The measurements of the temperature warping were usually made on days when a large variation in pavement temperature occurred, three complete sets of observations being made. The first measurements were made in the morning at a time when the observed temperatures in the upper and lower surfaces of the slab were equal. Under these conditions the slab was assumed to be flat and all subsequent measured distortions were referred to this plane as a base. The second set of measurements was made during the early afternoon, at the time when the temperature of the upper surface of the pavement was at or near the maximum and the slab was consequently warped downward at the edges. The final measurements were made early the following morning when the temperature of the upper surface of the pavement had reached its minimum value and the maximum upward movement of the edges of the pavement slab had occurred. The three sets of observations were sufficient to determine quite completely the shape of the slab under the conditions of maximum upward and downward temperature warping.

Some additional measurements were made for the purpose of establishing the relative movements of various parts of the slab, in tests that covered the full 24-hour cycle of temperature changes. Because of the frequency of the observations and of the time required to make one set, the measurements were limited to determinations of the transverse curvature of the slab panel along the free end, the center line and the transverse joint. The vertical displacemen at a few points was also measured with micrometer dials supported on long steel stakes driven into the subgrade. Most of these measurements were made at slab corners, and a few at the center of the edge. The measurements were made for the purpose of obtaining additional data on the movement of slab corners during the daily temperature cycle and for comparing, hour by hour, the displacements for slabs of various thicknesses.

Measurements of the warping caused by seasonal changes other than temperature were made with the clinometer in much the same manner as the other warping measurements. These measurements were made only on the 9-inch constant-thickness section. They were made at intervals of about 1-month throughout the year at times when the thermocouples indicated that no temperature differential was present. Because of the relatively short period of time during which this condition usually obtained it was not possible to extend the clinometer measurements over the entire slab. For this reason the observations were limited to what were considered to be the most important regions.

Measurements were started from a bench mark and carried across the two ends and along the longitudinal center line of one of the panels. Since it was necessary to maintain the same datum throughout the year special bench marks, the details of which are shown in figure 3, were installed near the edges of the slab on which these measurements were made. It will be noted that an electrical resistance thermometer is provided in the air space between the casing wall and the standard that carries the reference point. This permits a correction to be made for variations in the length of the standard resulting from seasonal temperature variations.

Measurements of the effect of temperature warping on load stresses.—The effect of the distortion of the pavement caused by temperature warping on the magnitude of the stresses produced by given wheel loads was studied by determining the critical stresses in the concrete for a given applied load with the slab flat and again in the condition of maximum upward and maximum downward warping. The loads were applied at the corner, the edge, and the interior of each slab upon which these tests were made.

The technique of applying the load and of measuring the strains was essentially the same as that followed the other tests. The loads were applied to the slab through a bearing block 8 inches in diameter. Since a warped slab was a requirement of the test, it was necessary to arrange the loading tank so as to avoid shading the concrete and thus interfering with normal warping. This was done by moving the tank over the end the adjoining section and placing a heavy I-beam

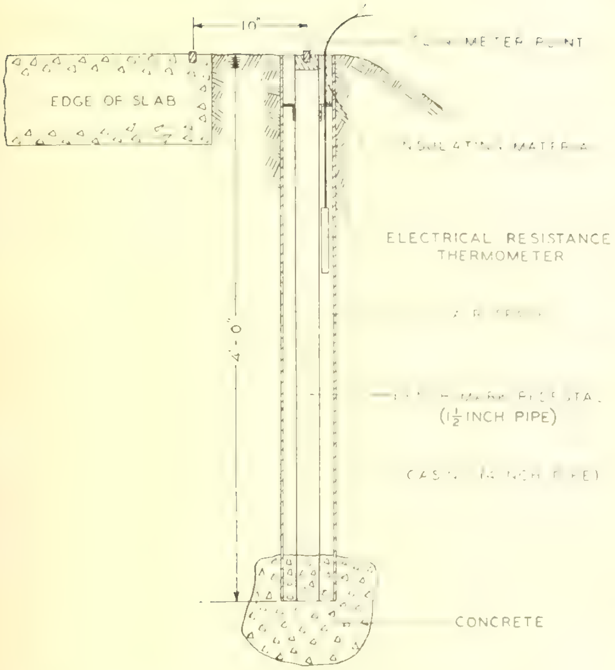

FIGURE 3.—DETAILS OF CLINOMETER BENCH MARK.

beneath and bearing against the tank with one end resting on a fixed support and the other end furnishing a reaction for the jack applying the load. Extension of the jack tended to raise the end of the I-beam and to lift the tank, the I-beam acting as a simple lever. The force exerted downward by the jack supplied the load to the test section. The equipment used for making these tests is shown in figure 4.

STRESSES CAUSED BY RESTRAINED TEMPERATURE WARPING DETERMINED

The magnitudes of the stresses created in the various parts of the pavement slab by restrained temperature warping were determined by comparing the deformations measured in the concrete at the points in question with the deformation at a point where there was little or no restraint.

Theoretically, at the edge of a pavement, there should be no warping stress in a direction perpendicular to the edge.[9] Practically, it is not possible to measure these strains at the edge, and in the test section the gages for this determination were placed with their centers 6 inches from the edge. A preliminary study showed that for slabs of these dimensions the stresses at the gage positions were all very small and that the least restraint exists at the mid-point of the free edge in the direction perpendicular to the edge. A strain gage placed at this point, perpendicular to the edge, will record most nearly the full deformation or volume change that the temperature change demands, while similar gages at other places will record different deformations, deformations that are modified by the magnitude of the restraint present at each gage position.

In the discussion that follows, measurements made with a gage in the position just described were considered as resulting from unrestrained warping and were used as a base for determining the amount of restraint existing at other parts of the pavement.

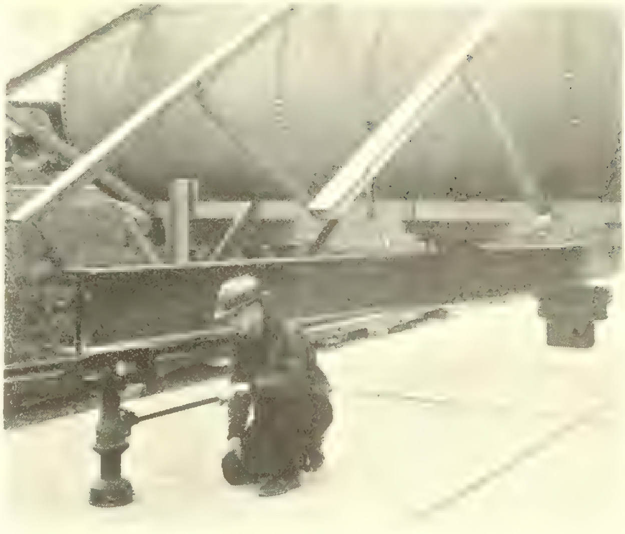

FIGURE 4.—METHOD OF APPLYING LOAD TO SLABS THAT HAD BEEN ALLOWED TO WARP.

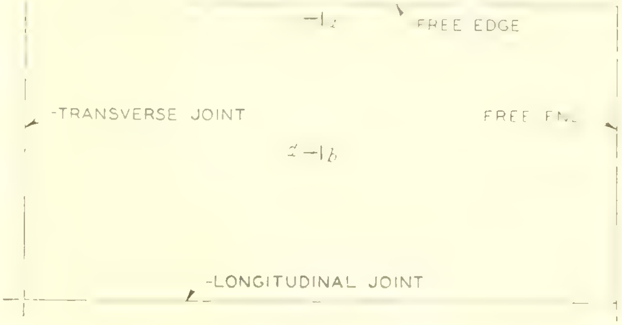

FIGURE 5.—PLAN OF 10- BY 20-FOOT SECTION SHOWING LOCATION OF THE FOUR TYPICAL STRAIN GAGES REFERRED TO IN THE DESCRIPTION OF THE METHOD OF DETERMINING RESTRAINED WARPING STRESS.

For example, in the plan of one of the 10- by 20-foot slabs shown in figure 5, four strain gage positions have been indicated by the letters *a*, *b*, *c*, and *d*. The direction of the line denoting the gage position shows the direction in which the deformation was measured. The deformation measured at *a* was considered to be the full deformation of unrestrained warping and the values measured at the other points were considered to be deformations that were modified by the restraint that existed. Any rise or fall of the temperature of the slab as a whole will cause equal volume changes at all of the gage positions and will not affect the determination of warping stresses to a measurable degree.

The four typical gage positions shown in figure 5 will be used to illustrate the method that was followed in making this study.

Since, at most points on the pavement slab, the concrete is stressed in more than one direction, consideration must be given to the effects of these other stresses on the deformations which are measured with the strain gage before the measured deformations can be converted into stresses. If an isotropic material is subjected to a force acting in a given direction, a certain unit deformation and a corresponding stress in the direction of this force will result. In addition, another deformation of lesser magnitude, of opposite sense and having a line of action perpendicular to that of the applied force, will be produced. The relation between the magnitudes of these two deformations is constant for a given material and is known as "Poisson's ratio." This constant provides the means for determining the effect of combined stresses.

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[9] See Analysis of Stresses in Concrete Pavements Due to Variations in Temperature, by H. M. Westergaard, Proc. Sixth Annual Meeting, Highway Research Board, 1927. Also see PUBLIC ROADS, vol. 8, no. 3, May 1927.

If σ_x represents the unit stress in the direction x, then the unit deformation caused by this stress would be measured by the expression $\frac{\sigma_x}{E}$, in which E is the modulus of elasticity of the material.

Similarly, if σ_y represents the unit stress in the direction y (perpendicular to direction x), the unit deformation in the direction y would be expressed by $\frac{\sigma_y}{E}$. Also a deformation in the direction x would be induced, the magnitude of which would be expressed by $\mu\frac{\sigma_y}{E}$, μ being Poissons' ratio for the material, and this deformation would be opposite in sense to that produced by σ_x.

In case the stresses σ_x and σ_y are acting simultaneously at a point, there will be in each direction a direct and an induced deformation that must be combined. If e represents the unit deformation caused by stress, then

$$e_x=\frac{\sigma_x}{E}-\mu\frac{\sigma_y}{E}$$

and similarly

$$e_y=\frac{\sigma_y}{E}-\mu\frac{\sigma_x}{E}$$

From these equations, the following expressions for unit stress are obtained:

$$\sigma_x=\frac{(e_x+\mu e_y)E}{1-\mu^2} \qquad (1)$$

and

$$\sigma_y=\frac{(e_y+\mu e_x)E}{1-\mu^2} \qquad (2)^{10}$$

DEFORMATIONS MADE UP OF THREE COMPONENTS

In this investigation the stresses caused by temperature warping were determined by comparing the deformations measured at various points on the slab surface over the period during which the temperature differential was changed and warping developed. The strain gages were generally installed at a time when no temperature differential existed and then allowed to remain until the maximum day or night temperature differential was observed. For these conditions the deformation recorded by each gage was the sum of three components combined algebraically. These component deformations are:

1. A change in length caused by the uniform change in the temperature of the slab as a whole. This change in length extends uniformly through the entire depth of the slab, creates no warping, and affects all strain gages equally.
2. The change in length of the upper surface of the pavement with respect to that of the lower surface, caused by the temperature differential created by the change in air temperature during the day. The differential in length caused by this temperature condition causes warping which, if the slab were weightless, would occur freely and would be unaccompanied by stress.
3. A deformation caused entirely by the bending stresses produced by the efforts of the slab to accommodate itself to the shape demanded by the temperature differential against the resistance of its own weight.

Since the measured deformations are not the result of combined stress alone it is necessary to modify somewhat equations (1) and (2) in order to adapt them to this method of determining the stresses produced by warping. In the following paragraphs the modified stress formulas are developed for each of the four gage positions that were shown in figure 5. The subscripts indicate the particular gage position that is being referred to.

δ = the unit change in the length of the concrete from all causes as actually measured by the strain gage.

ϵ = the unit change in the length of the concrete as measured by the strain gage but with a correction applied for the effect of the stress in a direction perpendicular to that being considered.

e = the unit change in length of the concrete caused by stress (unit strain).

μ = Poisson's ratio.

Referring again to the four gage positions shown in figure 5:

$$\epsilon_a=\delta_a-\mu e_c$$
$$\epsilon_b=\delta_b-\mu e_d$$
$$\epsilon_c=\delta_c$$
$$\epsilon_d=\delta_d-\mu e_b$$

Assuming that the concrete at point a is completely free to deform and using this deformation as a base, the strains at the four positions are:

$$e_a=0$$
$$e_b=\epsilon_a-\epsilon_b$$
$$e_c=\epsilon_a-\epsilon_c$$
$$e_d=\epsilon_a-\epsilon_d$$

If the proper values of ϵ are substituted in these formulas the strains in the concrete can be determined. These formulas multiplied by E, the modulus of elasticity of the concrete, are formulas for stress, expressed in terms of the measured deformations and the elastic constants of the material. They have the following form:

$$\sigma_a=0$$

$$\sigma_b=\frac{\delta_a-\delta_b+\mu(\delta_c-\delta_d)}{1-\mu^2}E$$

$$\sigma_c=\frac{\delta_a-\delta_c}{1-\mu}E$$

$$\sigma_d=\frac{\delta_a-\delta_d+\mu(\delta_c-\delta_b)}{1-\mu^2}E$$

Using the method described the stresses resulting from temperature warping during the day were determined for all of the gage positions shown in figure 6 for the 6- and 9-inch constant-thickness sections. Fo the conditions of warping that develop at night th stresses determined were those along the lines A–C an D–E and for the 6-inch constant-thickness section only.

The deformations in the concrete were measured wit the recording-strain gage that has been previousl described.[11] Because of the nature of the tests it wa necessary to expose the strain gages to a wide variatio in air temperature, varying from complete shade an

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[10] For a discussion of the action of combined stresses see Strength of Materials by S. Timoshenko, pt. 1, p. 58.

[11] See An Improved Recording Strain Gage, PUBLIC ROADS, vol. 14, no. 1 December 1933.

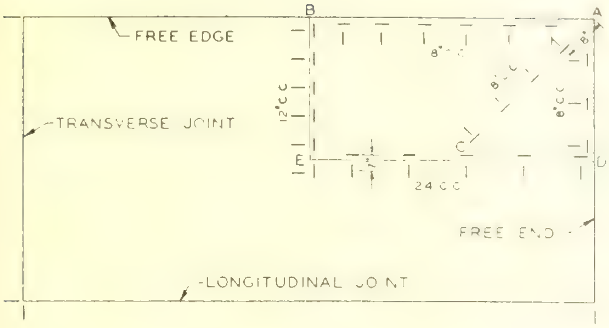

Figure 6.—Plan of 10- by 20-Foot Section Showing Location of All Strain Gages Used in Determining the Stresses Caused by Restrained Warping.

low temperature to full exposure to the sun's rays and high temperature, during the period that the deformations were developing. The gages are, by their design, compensated for temperature changes to an extent that makes the effect of ordinary temperature changes negligible. Also, since all gages in the test were exposed to the same temperature conditions, theoretically the comparison of deformations used to determine the stresses would be unaffected by temperature change.

In order to insure the greatest precision possible in these measurements, it was thought advisable to give all of the gages some measure of protection from the extreme temperatures to which they were exposed. Figure 7 shows a close-up view of one of the ventilated covers used for this purpose. These covers were made of sheet metal covered with corrugated paper board as insulation. The cover was painted white on the outside to minimize heat absorption and the ends were left open to allow the air to circulate around the gage. The shelters were made as small as possible in order that the shade afforded the gages would cover no appreciable portion of the slab.

The tests to determine the stresses produced by the restrained temperature warping were made during the spring and summer months for the day condition and during the fall months for the night condition, because the temperature data showed that the maximum temperature differential for each condition occurred at these respective seasons of the year.

STRESSES CAUSED BY RESTRAINED MOISTURE WARPING DIFFICULT TO OBTAIN

At the present time there are two chief obstacles that prevent the development of information concerning the stresses caused by restrained moisture warping comparable in scope to that developed on the subject of restrained temperature warping. The first of these, the inability to determine with any precision the character of the moisture distribution in the concrete, has already been mentioned. The second is the necessity of a very long period over which the strain observations must be continuous. In this investigation it has not yet been possible to make a determination of the stresses resulting from moisture warping. However, later in this report there is some discussion of the subject based on certain observations that have been made.

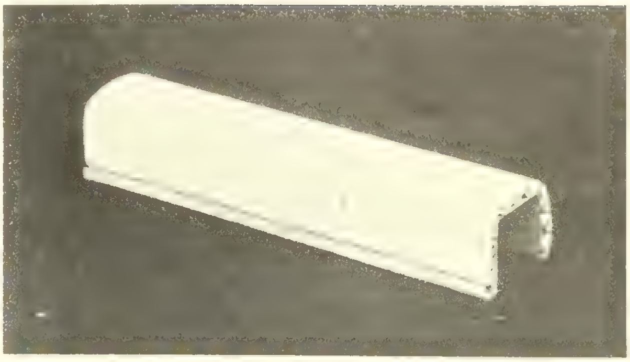

Figure 7.—Small Protective Cover Used Over the Strain Gages in Determining Stresses Caused by Restrained Warping.

DATA PRESENTED AND DISCUSSED

To give an idea of the weather conditions that prevail in the area where the tests were made, certain pertinent meteorological data covering the period from November 1, 1931, to November 1, 1932, are given in figure 8. This figure shows the daily and annual temperature variations, the monthly precipitation, and the monthly average relative humidity for a period that is believed to be typical. It will be noted that there is comparatively little freezing weather during the year, so little in fact that the earth beneath concrete pavement sections is rarely frozen. It was not possible to study the structural behavior of the sections for the condition of a frozen subgrade as extensively as was desired. The daily and annual temperature variations are large, however, and during the period of the tests a wide range of temperatures was encountered.

The temperature of the concrete in the pavement was measured on a number of days during the year for the purpose of studying the daily temperature variations of the concrete at different seasons. In some cases these observations were made at 1 or 2-hour intervals for the complete 24-hour period; in other cases they were started at about 4 a. m. and continued until late in the evening. From the data obtained it is possible to find the critical temperature conditions for each of the days and, inasmuch as the observations were made on days when large changes occurred, it is also possible to form an accurate idea of the occurrence of critical temperature conditions throughout the year. Table 1 contains typical data obtained in this manner from the 6- and 9-inch temperature slabs. This table shows the average temperature of the concrete when it was at the minimum and the maximum values for the day on which the observations were made. It also shows the actual measured temperatures in the upper and lower surfaces of the two slabs.

The tabulated difference between these two temperatures may not be the effective temperature differential, since the temperature gradient between the two surfaces may or may not be uniform. This point will be discussed more fully later.

Several interesting facts are brought out in this table. It is shown that the average slab temperature varies about 75° F. during the year. This figure is important because it is the value that controls the magnitude of the annual change in length of the pavement caused by temperature changes. The maximum surface temperature recorded during this period was 112.5° F. The data show that the temperature of the 6-inch slab is, as a whole, much more responsive to variations in air temperature than is the 9-inch slab, yet the actual temperature differential between the upper and lower surfaces is always greater for the thicker slab. Under certain maximum conditions the value of the tem-

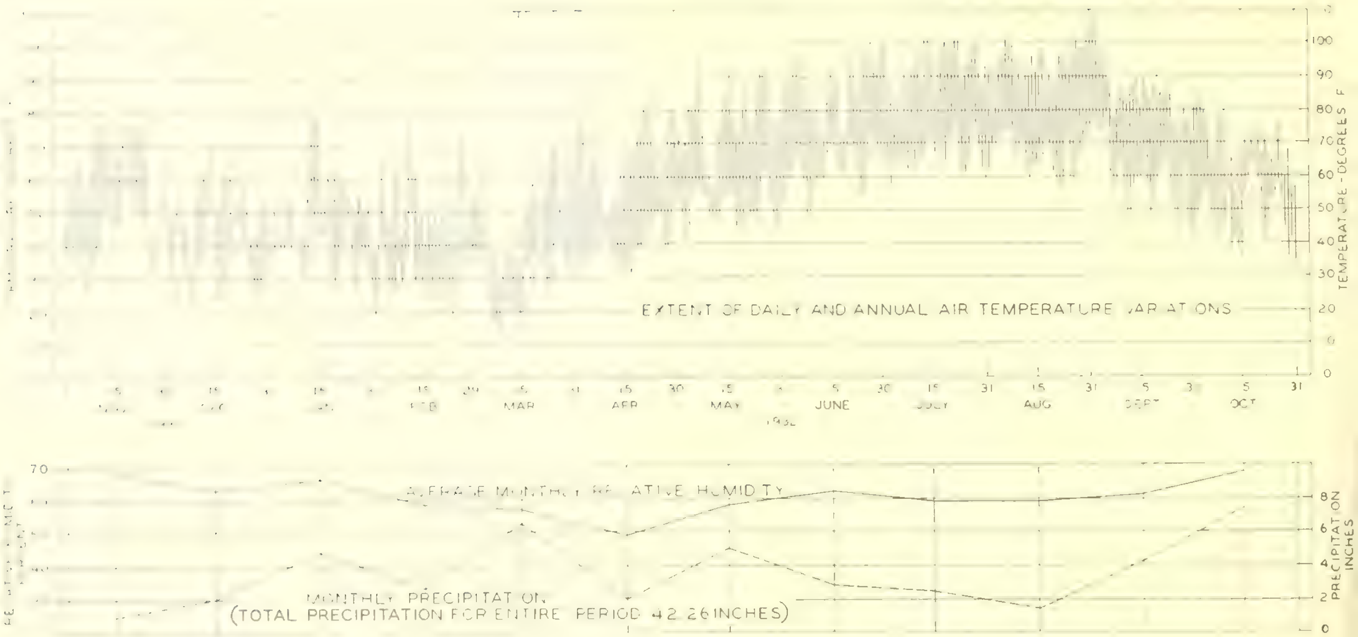

Figure 8.—Annual Variations in Air Temperature, Relative Humidity, and Precipitation.

Table 1.—*Observed temperatures in concrete pavements (degrees F.)*

Date	Average temperature of concrete				Maximum temperature values											
	6-inch slab		9-inch slab		Night						Day					
					6-inch slab			9-inch slab			6-inch slab			9-inch slab		
	Minimum	Maximum	Minimum	Maximum	Bottom	Top	Difference	Bottom	Top	Difference	Bottom	Top	Difference	Bottom	Top	Differ ence
1931																
Nov. 24		65.1		62.1							59.2	70.0	10.8	55.6	69.1	13
Nov. 25	52.2		53.0		56.3	52.3	4.0	57.2	52.0	5.2						
1932																
Feb. 1	26.6	41.2	29.4	40.8	31.1	24.4	6.7	36.1	24.6	11.5	36.7	44.9	8.2	35.8	45.3	9
Apr. 14		67.6		63.6							59.7	81.0	21.3	50.0	81.0	31
Apr. 15	39.9		42.3		43.0	36.5	6.5	48.9	39.7	9.2	56.8	76.1	19.3	51.6	73.9	22
June 8	65.5	91.9	63.5	84.0	70.3	63.9	6.4	68.9	61.3	7.6	80.2	102.7	22.5	69.3	96.1	26
July 13	75.4	102.7	76.7	96.8	79.9	75.4	4.5	81.3	75.6	5.7	90.9	112.5	21.6	82.8	111.7	28
Aug. 5	70.7	98.4	72.0	93.7	73.8	68.4	5.4	75.4	68.0	7.4	81.3	101.7	20.4	80.2	105.8	25
Sept. 1	77.5	100.2			78.8	76.1	2.7				90.7	106.3	15.6			
Oct. 11	60.3	70.0			61.0	59.7	1.3				64.8	76.5	11.7			
Nov. 4	37.4	56.7			40.5	34.9	5.6				46.4	58.3	11.9			
1933																
Jan. 3	28.5	40.6			31.1	27.0	4.1				32.0	40.5	8.5			
Feb. 24	37.0	58.8			39.4	35.1	4.3				49.5	65.1	15.6			
Apr. 13	42.8	69.4			45.9	39.9	6.0				56.8	81.1	24.3			
May 19	59.7	85.6			63.0	56.7	6.3				74.5	96.1	21.6			
June 2	60.1	86.7			63.0	57.4	5.6				72.7	94.1	21.4			
Aug. 15	69.8	92.8			73.2	67.5	5.7				80.6	99.3	18.7			

perature differential in the 9-inch slab is nearly 50 percent greater than the corresponding value in the 6-inch slab. The maximum differential observed at any time in the 6-inch section was 24.3° F., while in the 9-inch slab it was 31° F.

RANGE OF DAILY PAVEMENT TEMPERATURES DETERMINED

From the data that are summarized in table 1, four individual cycles of observations were selected for graphical presentation to illustrate the range and character of the daily and annual variations in temperature that occur in concrete pavements in this locality. Each of the four cycles chosen is typical for the season in which it occurred although, as mentioned before, the observations were made on days when there were large variations in the temperature the pavement for that particular season. In figu 9, 10, and 11 these data are presented in different wa each graph being arranged to bring out the significan of the data with respect to some particular point.

The character of the daily variation of temperat throughout the depth of the 6- and 9-inch slabs shown in figure 9 by means of gradient curves tak periodically throughout the day. It is apparent th the variations are much greater during the day when t sun is shining than at night, and also that the great variations occur during the warm seasons of the ye Both of these effects are caused by the absorption heat from the sun's rays, and the more intense sunlight the greater will be the effect.

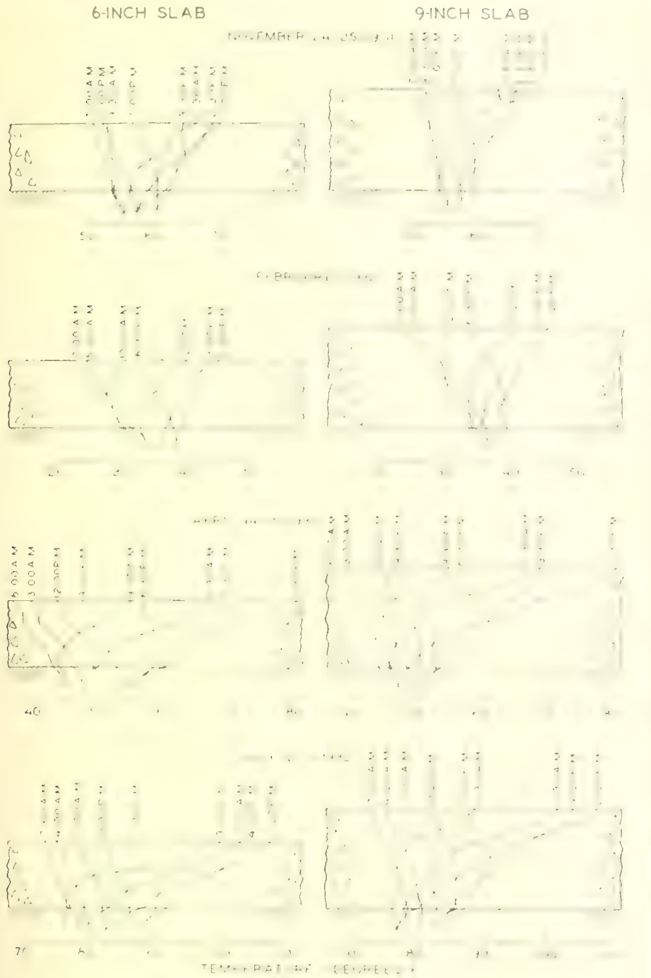

FIGURE 9.—TYPICAL DAILY AND SEASONAL TEMPERATURE VARIATIONS IN CONCRETE PAVEMENT SECTIONS.

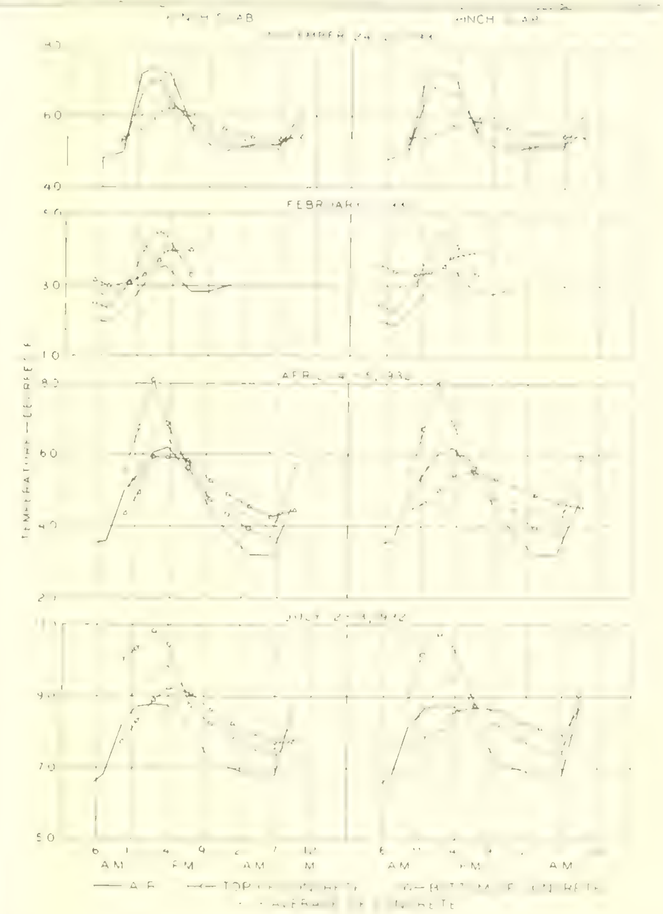

FIGURE 10.—RELATION OF AIR TEMPERATURE TO PAVEMENT TEMPERATURE.

Figure 9 shows why the difference between the temperatures of the two surfaces of a pavement is not necessarily the effective temperature differential. It is probable that an average line drawn through each of the gradient curves shown in this figure would give a better approximation of the effective differential. This is the method that has been used for determining the values of the differential given in this report. It should be noted that in the early morning and in the afternoon when the maximum temperature differentials occur, there is approximately a straight-line gradient in temperature between the upper and lower surfaces of the concrete. These are the two times of the day that are most important in the determination of stresses caused by warping.

It is not unusual at certain seasons of the year to find that the absorption of the heat from the sun has caused the temperature in the upper surface of the slab to be from 10° to 20° F. higher than the air temperature. The effect is greatest when the angle of incidence of the sun's rays to the pavement surface is greatest. In figure 10 the relation between the air temperature, the average slab temperature, and the temperatures of the two surfaces are shown for typical days at four different times during the year.

As previously explained, the average pavement temperature is obtained by averaging the values obtained from all of the thermocouples throughout the slab depth. For this reason the average temperature may not be equal to the mean of the upper and lower surface temperatures. These curves show the rapidity with which the temperature of the upper surface changes during the day and the extent to which it rises above air temperature during certain parts of the year.

FACTORS AFFECTING PAVEMENT TEMPERATURE DISCUSSED

During the warmer seasons of the year even the average temperature of the concrete rises above the air temperature for considerable periods of time. The temperature of the concrete on any one day is controlled not only by the air temperature on that day but also by several other factors such as the angle of incidence of the sun's rays, the previous temperature conditions, particularly as they affect the temperature of the subgrade, the moisture conditions, and the humidity of the atmosphere.

An example of the effect of these other factors is found in the data in figure 10 for February 1, 1932. It will be observed that the temperatures of both surfaces of the slab are higher than the air temperature on this date. An examination of the temperature data for the period showed that for several days preceding February 1 higher temperatures had prevailed. The heat absorbed by the concrete and the subgrade during the warmer period had not been dissipated when the observations shown in the figure were made.

The observed differences in temperature between the upper and lower surfaces of the 6-inch and 9-inch

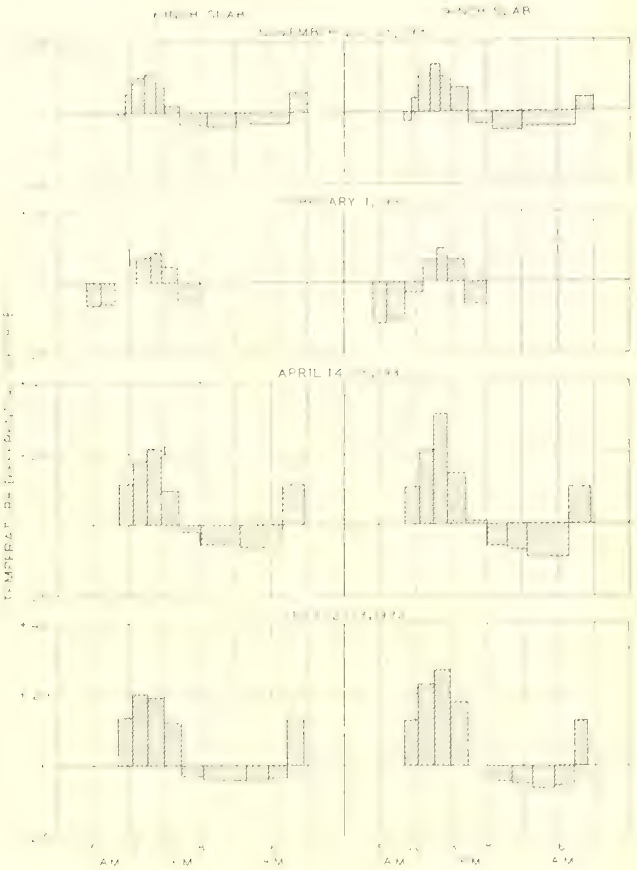

Figure 11.—Typical Daily and Seasonal Variations of Temperature Differentials in Concrete Pavement Sections.

slabs, for the 4 typical days, are shown in figure 11. The positive values indicate differences when the upper surface of the pavement is warmer than the lower surface, while the negative values apply to the opposite condition. The principal purpose of this chart is to assist in tracing the variations, during the day and during the year, of the temperature differences that cause warping.

It will be noted that during the spring and summer months when the daily changes in the temperature of the concrete are large, the difference between the maximum positive temperature differentials in the 6- and 9-inch constant-thickness slabs is approximately proportional to the difference in slab depths. During the late fall and winter months, however, when the daily changes in the temperature of the concrete are much smaller, the difference between the positive temperature differentials is much smaller. The maximum difference between the positive temperature differentials of the two slabs appears to be in the spring. At this time, although the intensity of the sunlight is very great, the subgrade is still relatively cold and the subgrade under the 9-inch slab warms up more slowly than that under the 6-inch slab. The negative temperature differentials are so small and vary so much from day to day that it is difficult to find any direct relation between these temperature differentials in slabs of different thicknesses and at different times of the year.

Mention was made previously of thermocouples that were installed especially to determine the effect of a thickened-edge cross section on the magnitude of the temperature differentials developed for various conditions of air and subgrade temperature.

Table 2.—*Observed maximum temperature differentials between the upper and lower surfaces of concrete pavement sections*

Date, 1934	Maximum temperature differential				
	At edge of constant-thickness sections		Thickened-edge section, 9-6-9 inch		
	6-inch slab	9-inch slab	Edge	18 inches from edge	36 inches from edge
	°F.	*°F.*	*°F.*	*°F.*	*°F.*
Apr. 3		......	27	25	21
Apr. 5		......	21	21	20
Apr. 6		20	18	17	15
Apr. 8	......	25	25	25	22
Apr. 10	15	23	26	24	21
Apr. 15	17	26	25	25	22
Apr. 18	18	27	27	25	22
Apr. 21	18	24	22	21	20
Apr. 22	14	24	21	20	19
Apr. 24	21	31	29	27	20
Apr. 29	15	24	25	23	21
May 1	18	28	28	25	25
May 5	23	32	33	31	27
May 7	24	31	30	30	26
May 8	26	27	28	24	22
May 9	18	25	24	22	20
May 13	21	29	31	28	24
May 14	16	24	27	26	24
May 18	21	30	30	28	25
May 19	20	26	29	27	24
May 20	23	33	32	30	28
May 21	20	31	32	29	26
May 24	19	25	25	23	21
May 28			23	25	21
June 1	21	30	30	28	26
June 3	16	29	28	28	22
June 4	19	27	27	27	23

Table 2 contains data obtained from measurements made on three of the test sections during a 2-month period in the spring of 1934. Each temperature differential shown is the maximum that occurred during the particular day, and the observations were made when there were large temperature variations for the season of the year. The second and third columns of the table show the observed differentials at the edges of the 6-inch and 9-inch constant-thickness sections, respectively, while the last three columns contain comparative data at three points along the cross section of a representative thickened-edge section.

A comparison of the values in the second with those in the fourth column shows the relation between the temperature differential at the edge of a 6-inch slab that is not thickened at the edge and that of one that is thickened to 9 inches. A similar comparison of the data in the third and fourth columns shows the relation between the differential of temperature in the 9-inch edge of a constant-thickness slab and that in the 9-inch edge of a thickened-edge cross section. These comparisons show that the temperature differential that develops at the edge of a 9–6–9 thickened-edge design is approximately equal to that in the edge of a 9-inch constant-thickness section and is approximately 45 percent greater than that in the edge of a 6-inch constant-thickness section. It is indicated by these data, therefore, that increasing the edge thickness of a pavement may be expected to result in a proportionate increase in the temperature differential in the edge region of the slab.

The data in the last three columns show the temperature differentials observed at distances of 2, 18, and 36 inches from the free edge of the 9–6–9 section. The data obtained at a point 36 inches from the edge probably represent very closely those that would be found throughout the 6-inch interior portion of a slab of this design. Comparing the values in the fourth column with those in the sixth, it is indicated that the differential in the edge of this section averaged, for the period of the measurements, about 20 percent greater than that at a point 36 inches from the edge. At a point 18 inches from the edge the increase was approximately 13 percent. The edge depth is 50 percent greater than the depth 36 inches from the edge and, of course, the increase in depth at 18 inches from the edge is one-half of this or 25 percent. Hence, it appears that the increase in the temperature differential near the edges over that in the interior of this thickened-edge design is less than would be expected in view of the relation of center depth to edge depth. It is believed that this is due to the stabilizing influence of the earth shoulder along the vertical face of the slab edge that acts to reduce somewhat the temperature differential. This would apply to both thickened-edge and constant-thickness sections, although the result will probably be less as the edge thickness of the sections is reduced.

EXPANSION AND CONTRACTION OF PAVEMENT SLABS MEASURED

At the same time that the temperature determinations were made the change in length of one of the 40-foot test sections was measured. In figure 12 the variations in length of this section are shown, together with the simultaneous variations in the average temperature of the concrete. These data are plotted to a common base for the same four cycles considered in the discussion of the temperature data. It will be noted that there is a very close phase relation between the temperature and expansion curves, there being little or no lag even at those times of the day when the temperature is changing most rapidly. The lag of the average pavement temperature with respect to air temperature has already been shown in figure 10.

These data show that for a given average temperature the pavement does not always have the same length. For example, at an average temperature of 60° F. in November the change in length, with respect to a certain base, was −0.0105 inch, while in April it was +0.017. This indicates that in the 5 months between November and April the length of the slab has increased 0.0275 inch from some cause other than temperature changes.

In the vicinity of Washington, D. C., the mean monthly precipitation was averaged for the period covered by the observations (1931 to 1934, inclusive) and it was found to be 4.6 inches for the summer months (April to September, inclusive) and 3.1 inches for the winter months (October to March, inclusive). Thus the precipitation was greatest for the period when the slabs were found to be shortest for a given temperature. However, evaporation measurements made in this locality a number of years ago by the Weather Bureau show that during the summer months the loss from a free-water surface averages more than 6 inches per month, while during the winter the loss through evaporation is very small.

This suggests that beginning in the late fall there should be a progressive increase in the moisture content of the soil that continues until the spring temperature rise begins, after which there should be a corresponding progressive decrease. Such soil-moisture determinations as were made confirmed this idea. This being true, it seems reasonable that during the summer months lowered moisture content in the subgrade and a relatively high evaporation rate reduce the moisture content of the concrete and that the opposite conditions in the winter will increase the moisture content of the concrete and thus account for the observed volume changes.

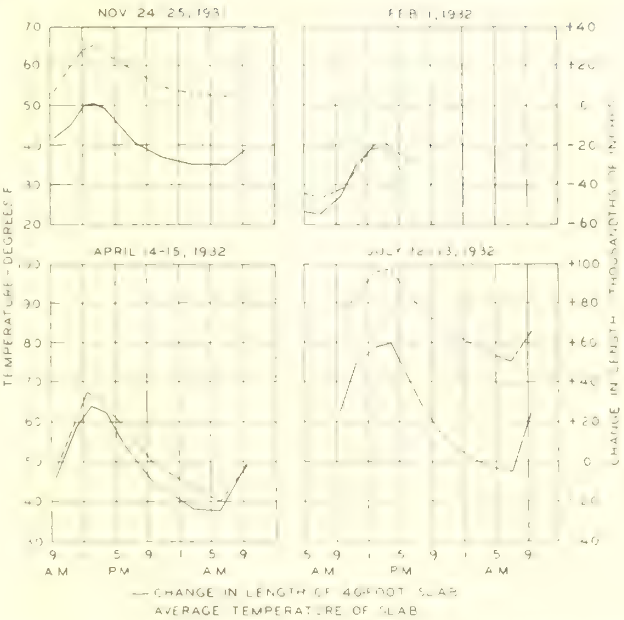

FIGURE 12.—VARIATIONS IN SLAB LENGTH COMPARED WITH VARIATIONS IN AVERAGE CONCRETE TEMPERATURE.

In order to separate the changes in length resulting from these two different causes so that the magnitude of each could be determined, the data obtained during the various daily cycles of observations were grouped on a single sheet and all referred to a common base for comparison in the manner shown in figure 13. The changes in slab length measured on any given day are plotted against the corresponding average concrete temperatures. The plotted points pertaining to a day's observations are averaged with a straight line, the slope of which is the coefficient of thermal expansion for the slab as a whole, as indicated by those particular data. Since all of the data are plotted to a common base, the spread horizontally between these daily average lines is, when taken at a common temperature, a measure of the expansion resulting from causes other than temperature changes.

Figure 13 contains a few typical data plotted in this manner for the purpose of demonstrating the method of analysis. In this graph the coefficient of thermal expansion of the concrete, as determined in the laboratory, is shown by the slope of the dash line through the center. It will be noted that the lines showing the daily averages appear to converge slightly toward the dash line. Throughout the data this convergence varies systematically with the season, indicating that the coefficient of thermal expansion determined from the daily observations of slab expansion undergoes a small annual variation. The cause of this was not determined but it seems likely that the coefficient of thermal expansion effective in the slabs varies slightly with the moisture content of the concrete.

It is possible also that warping in the slab introduces a small error in the determination of the slab length, and such an error, if present, would tend to vary systematically in the same manner as does the extent of the warping. The possibility of subgrade resistance variation being a factor was also considered but calculations indicate that the variations in subgrade resistance caused by variations in subgrade moisture would produce an effect of negligible magnitude.

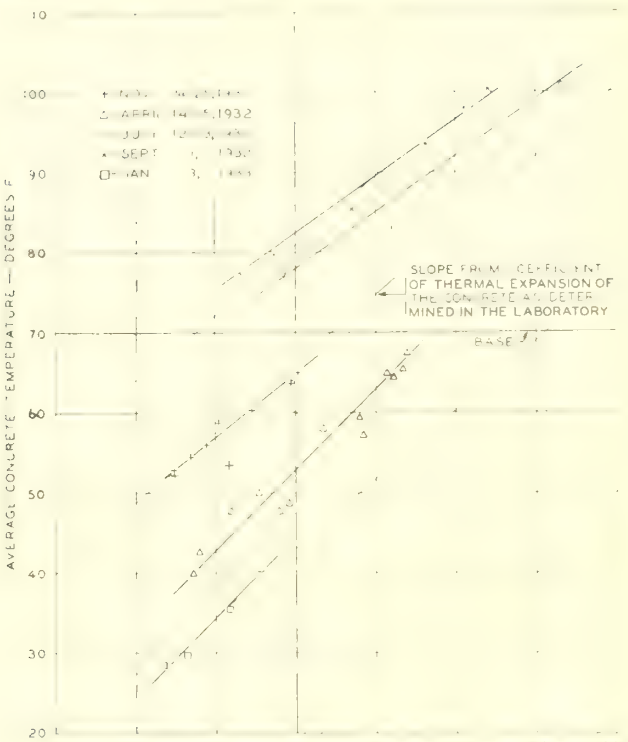

FIGURE 13.—RELATIONS BETWEEN AVERAGE CONCRETE TEMPERATURE AND CHANGE IN LENGTH OF PAVEMENT SLAB FOR VARIOUS PERIODS DURING THE YEAR.

In order to eliminate, to the fullest extent possible, any error caused by this slight convergence, the determination of spread was made by extending auxiliary dotted lines from the center of gravity of each day's observations and parallel to the dash line previously mentioned to an intersection on a common temperature line, chosen arbitrarily at 70° F. in this instance. The distance between intersections is a measure of the length change attributed to moisture.

CHANGES IN PAVEMENT LENGTH CAUSED BY VARIATIONS IN MOISTURE CONTENT DETERMINED

In figure 13 data from only five sets of observations are shown. Actually, observations were made on a great many days and all of the data were analyzed in this way. From this analysis the variations in the length of the 40-foot test section resulting from variations in moisture content were obtained at frequent intervals during a 5-year period. The change in length resulting from variations in moisture content alone during this time is shown in figure 14, plotted with respect to the original length at the time that the concrete took its initial set. The measurements of length change were made on one section with the embedded telemeter during the period between September 1930 and August 1932, and with the micrometer on another section during the period between November 1931 and September 1935. During the 8 months between November 1931 and August 1932, data from both methods are available and there is very close agreement between them.

This graph indicates that there is an annual cyclic variation in length caused by variations in moisture content, the sections being longest (for a given temperature) during the winter and shortest during the summer. The magnitude of this length change is appreciable, corresponding to that which would be caused by a temperature change of 20° to 40° F. for the different years during which the measurements were made. In a 40-foot section this variation in length amounts to about 0.05 to 0.10 inch.

It will be noted that there is a considerable variation in the extent of this length change for the different years, the smallest change occurring in 1930–31 and the largest thus far observed in 1932–33. It is believed that the variation in the magnitude of the length change from year to year is the result of the particular precipitation and evaporation conditions that happened to prevail. The precipitation record is as follows:

	Inches
1930	21. 7
1931	33. 5
1932	49. 5
1933	49. 1
1934	51. 1

Unfortunately, there is not a similar record of the annual evaporation at the site of the tests. Nor was it practicable to determine the annual variation in the moisture content of the concrete over this period. As previously stated, there was no dependable method available for determining the moisture content of the concrete in the pavement. Using fragments broken from the specimen slabs and determining the moisture content by drying in the laboratory, it was found that the concrete contained 3.5 percent moisture during the summer and 3.8 percent during the winter. These values should be considered as nothing more than an indication of the variation of the moisture content of the pavement.

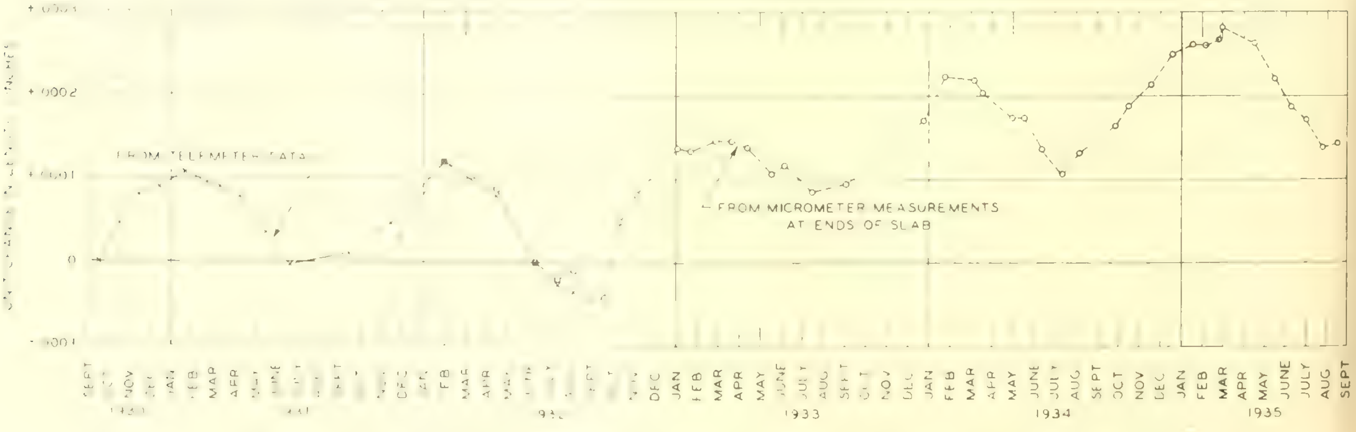

FIGURE 14.—ANNUAL VARIATIONS IN PAVEMENT LENGTH CAUSED BY CHANGES IN MOISTURE CONTENT.

The data presented in figure 14 show a definite progressive increase in the length of the pavement that has become more marked during the fourth and fifth years. The slab, during the summer of 1934, was longer than in the summer of 1931 by 1 part in 10,000. This may seem to be a small amount but it represents a length gain of 6.3 inches in a mile of pavement. Looking at it another way, if the slab ends were completely restrained such a length gain might develop a compressive stress of several hundred pounds per square inch.

Although this tendency for concrete to "grow" in the presence of moisture has long been known and has been the subject of much speculation and experiment, the phenomenon is not well understood and the ultimate extent of the growth cannot be predicted for given materials and conditions of exposure with the information that has thus far been developed.

COEFFICIENTS OF THERMAL EXPANSION FOR CONCRETE DETERMINED BY BOTH LABORATORY AND FIELD TESTS

In figure 13 the variation in slab length was compared with the variation in average concrete temperature for typical cycles of daily observation. Such data can be used to determine the coefficient of thermal expansion that is effective for the slab as a whole. In figure 15 this has been done. The graph was constructed by plotting the maximum change in length for each daily cycle against the corresponding change in the average temperature of the slab. Each daily cycle of observations thus supplied one point for the figure. Through these points a straight line was drawn to average the data. The slope of this average line is the coefficient of thermal expansion that affects the slab as it lies on the subgrade. The value of the coefficient as obtained by the method just described is 0.0000047 inch per inch per degree F. from the telemeter data, and 0.0000049 inch per inch per degree F. from the micrometer measurements at the ends of the slab. These values compare with one of 0.0000048 determined for the same concrete in the laboratory.

The method used in the laboratory determinations was described in part 1 of this series of papers. It consists, briefly, of the casting of a 12 by 24-inch cylindrical specimen in a moisture-tight copper container with a telemeter or recording strain gage of the electrical resistance type embedded in the center of the specimen. As previously noted, each telemeter contains a resistance thermometer, thus permitting simultaneous observations of deformations and temperatures.

After the concrete had hardened and cooled, the sealed cylinder was placed in water baths at 32° F. and 110° F. alternately a number of times, remaining in each until complete temperature equilibrium was attained. Since loss of moisture is prevented by the copper jacket, the difference in length measured by the telemeter under these conditions is the result of temperature change and from it the value of the coefficient of thermal expansion was obtained. The method was later used for determining the thermal coefficient for the concrete in connection with the elaborate test program on the Rogue River bridge.[12]

The close agreement between the coefficients of thermal expansion for the pavement and those obtained with unrestrained concrete in the laboratory indicates that the stresses in the pavement caused by the resistance of the subgrade to horizontal slab movement must be very small.

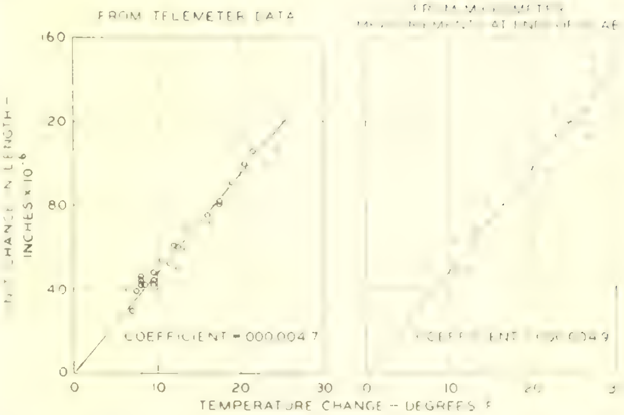

FIGURE 15.—RELATIONS BETWEEN TEMPERATURE CHANGE AND EXPANSION FOR CONCRETE PAVEMENT SLAB.

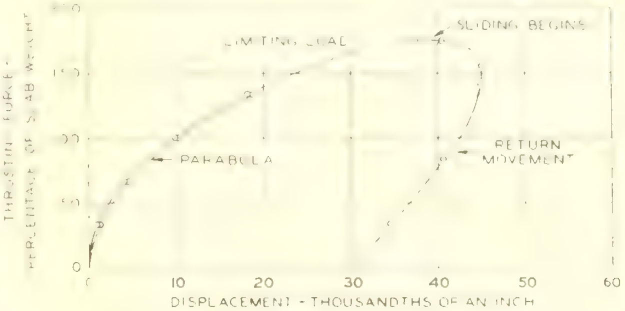

FIGURE 16.—TYPICAL FORCE-DISPLACEMENT CURVE FOR HORIZONTAL SLAB MOVEMENT.

RESISTANCE OF SUBGRADE TO HORIZONTAL SLAB DISPLACEMENT MEASURED

It will be recalled that in the earlier mention of these tests it was stated that the procedure adopted as a result of the preliminary study was one that would subject the subgrade to the same manipulation, as nearly as possible, as that which it receives under a pavement.

The test slabs were moved a distance of approximately 0.040 inch during a period of approximately 6 hours and they were moved in opposite directions on alternate days. The displacement of the slab was measured immediately after the application of each increment of thrust and again just before the next increment was applied.

Figure 16 shows typical data resulting from one of these tests. In this instance the horizontal force, or thrust, was applied at the rate of 50 pounds every 10 minutes until a total of 2,100 pounds caused visible sliding to begin. As soon as this point was reached the reduction of the force was started and continued at the rate of 100 pounds every 10 minutes until all horizontal thrust had been removed.

The curve shows the force-displacement data for the entire test. As the increments of force were applied the successive increments of displacement increased in magnitude in a ratio that closely approximates a parabola as shown by the dotted line adjacent to the curve. During this period there was no visible evidence of the concrete sliding on the subgrade. As the force being applied reached a value of approximately 150

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[12] Application of the Freyssinet Method of Concrete Arch Construction, by Gemeny and McCullough. Tech. Bul. No. 2, Oregon State Highway Department, 1933.

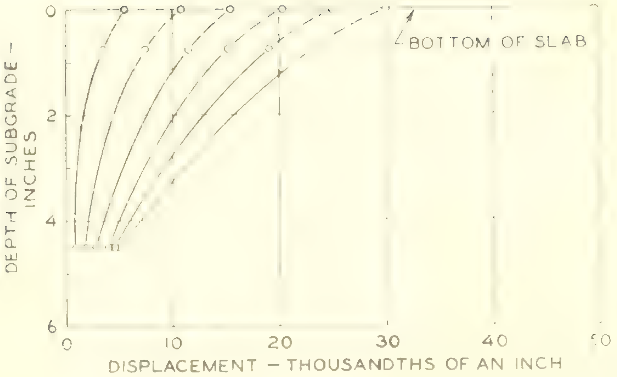


Figure 17.—Movement of Subgrade Compared with Slab Displacement.

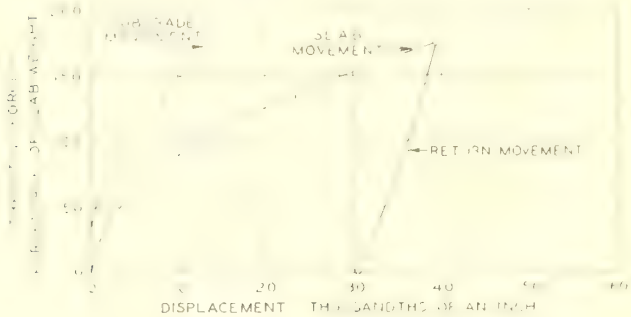


Figure 18. -Relative Movements of Pavement and Subgrade for a 6-Inch Slab.

percent of the weight of the test slab there is evidence that a condition of actual sliding is impending.

In this test free sliding occurred with a thrust equal to 175 percent of the slab weight and a force greater than this could not be applied. Reduction of this force started a movement of the slab in the opposite or return direction, and in this test it will be observed that complete removal of the thrust caused a recovery of about one third of the total displacement. This recovery is believed to result from elastic deformation of the subgrade caused by the adherence of the earth to the bottom of the slab. When the slab moves there is an actual movement of the subgrade with it.

The character of the horizontal movement that occurs in the subgrade when there is a displacement of the slab is indicated by the test data in figure 17. In these tests micrometer dials measured the horizontal soil movement at depths of three-fourths inch and 4½ inches as the slab was being moved. The particular test for which the data are shown was one in which a slot or groove 5 inches deep had been cut vertically into the subgrade just ahead of the leading edge of the slab. The presence of this groove probably affected somewhat the magnitude of the displacements produced by a given thrust.

Figure 18 shows the average data obtained from a number of tests in which the "bending" of the subgrade was measured without the disturbing influence of the groove just mentioned. The subgrade displacement in this figure is the average of measurements made at both sides and the center of the leading edge of the slab and at a depth of three-fourths inch. In will be observed that at this depth the subgrade movement is about 30 percent of the slab displacement. The return movement of the slab after the release of the thrust is about 25 percent. In many cases the percentage of return was greater than this, ranging up to about 40 percent of the total displacement.

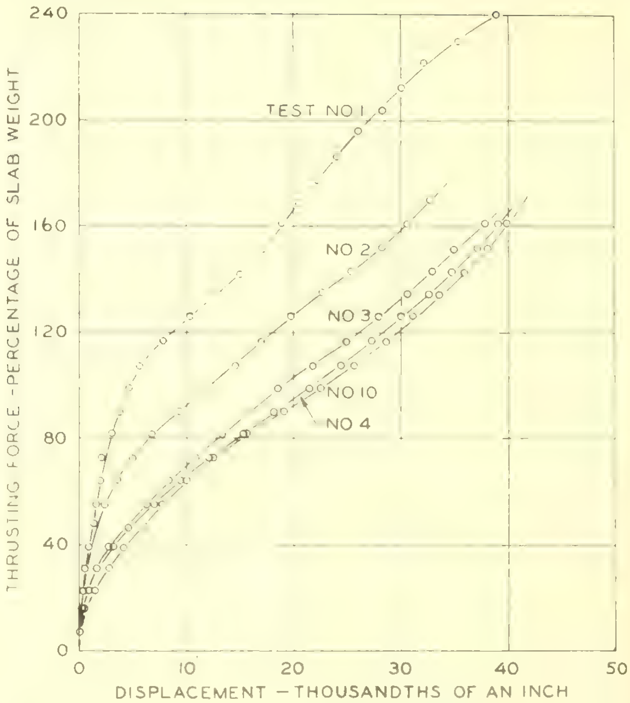


Figure 19.—Force-Displacement Curves for Repeated Tests on 6-Inch Slab.

A few tests were made to determine how long the subgrade would maintain this elastic resistance that caused it to move the slab back toward its original position, and it was found that after the horizontal thrust had been kept at a constant value for 8 days and then released, the return movement was practically as great as if the slab had been displaced but momentarily. This indicates that the subgrade tested had a high degree of elastic action for small displacements.

Tests were made in which the slab was displaced a given amount several times, in exactly the same manner each time. The data obtained are shown in figure 19 and it appears that with each successive application there is a reduction in the amount of thrust required to produce a given movement. A condition of practical stability seems to have been reached, however, after a comparatively small number of movements. These data indicate that, for a given subgrade, the resistance to slab movement may be greater for the first movements of the newly constructed pavement than it is later when the concrete has expanded and contracted a number of times.

EFFECT OF SLAB WEIGHT ON RESISTANCE TO HORIZONTAL DISPLACEMENT INVESTIGATED

As previously mentioned, some effort was made to determine the effect of slab weight on the resistance to horizontal displacement by means of tests with slabs of 2, 4, 6, and 8-inch thicknesses.

In making these tests the procedure was first to move the slabs forward and backward through a distance of 0.040 inch several times until it appeared that the subgrade resistance had become stabilized for displacements of this magnitude. The test slabs were then moved through distances of 0.070 and 0.100 inch in the same manner. There was a tendency for all of the slabs to continue to slide under the action of

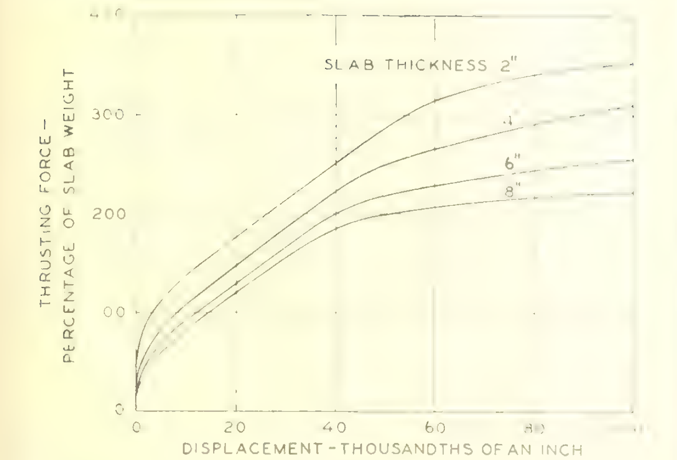


FIGURE 20.—FORCE-DISPLACEMENT CURVES FOR 2-, 4-, 6-, AND 8-INCH SLABS.

thrusting forces that would produce the 0.100 inch displacement, and these may be considered as the maximum horizontal resisting forces that could be developed.

Figure 20 shows the relation between thrusting force and displacement for each thickness of slab. The data for displacements of 0.040 inch or less were obtained during the tests in which the maximum displacement was 0.040 inch, and the data for displacements of more than 0.040 inch were obtained from the tests in which the slabs were moved either 0.070 or 0.100 inch.

It is apparent from this figure that the forces necessary to move the slabs of different thicknesses do not bear a constant relation to the respective slab weights for the subgrade in question. In this connection it is well to bear in mind that the total displacement of the slab may be composed of two parts: First, an elastic or semielastic displacement of the soil particles with no sliding of the slab as such; and second, an actual slipping of the slab over the soil surface. The first action necessarily begins as soon as slab displacement starts. Whether or not the second action follows depends upon the nature of the soil and the magnitude of the displacement.

The relation between thrusting force and slab thickness for displacements of several magnitudes is shown in a different manner in figure 21. Again it is apparent that the magnitude of the thrusting forces required is not directly proportional to the respective slab thicknesses (or weights). If it were, the sheaf of curves in this figure would all be straight lines passing through the origin of the graph. To illustrate the variation in another way, if all of the resisting forces were summed up in a coefficient to be applied to the weight of the slab, the value of this coefficient, instead of being constant, would vary with slab weight and displacement as given in table 3.

TABLE 3.—*Variations of subgrade coefficients of resistance to displacement with slab weight*

Slab thickness	Slab weight	Coefficients of resistance to displacement for displacements of—					
		0.01 inch	0.02 inch	0.03 inch	0.04 inch	0.07 inch	0.10 inch
Inches	*Lbs. per sq. in.*						
8	0.67	0.8	1.2	1.5	1.8	2.1	2.2
6	.50	.9	1.3	1.6	2.0	2.4	[illegible]
4	.33	1.1	1.5	1.8	2.2	2.8	3.1
2	.17	1.3	1.7	2.1	2.5	3.3	[illegible]

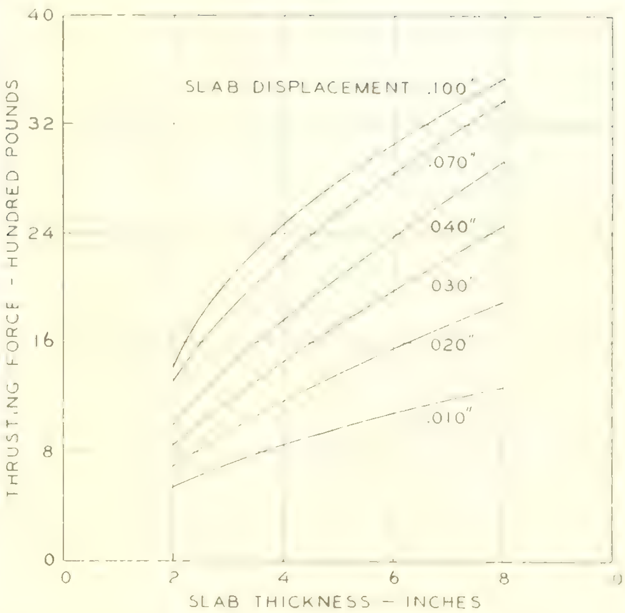


FIGURE 21.—RELATIONS BETWEEN SLAB THICKNESS AND RESISTANCE TO DISPLACEMENT

The data indicate that a weightless slab in intimate contact with the subgrade might, under certain conditions of soil and moisture, develop a very considerable resistance to horizontal displacement.

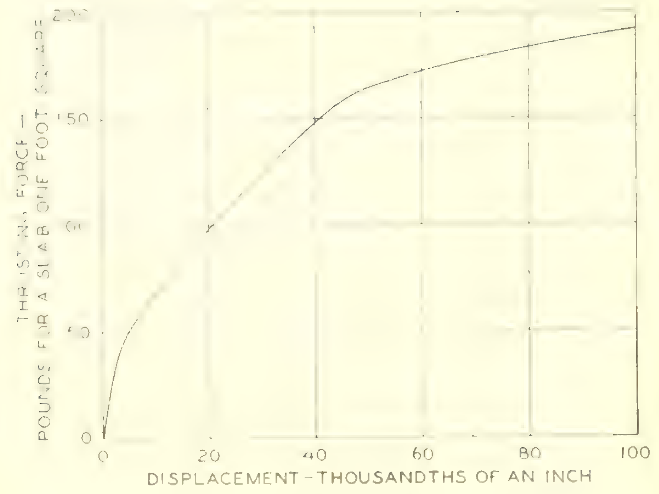
From the results of these studies it seems reasonable to conclude that the resistance offered by the subgrade to the horizontal movement of a pavement slab is composed of two elements: (1) A resistance caused by an elastic or semielastic deformation within the soil; and (2) a resistance that approximates closely that of simple sliding friction. The first of these appears to be independent of slab weight, while the second varies directly with slab weight. It seems quite probable that the relative magnitudes of these two components will vary with different subgrade soils, although no data on this point have been obtained.

METHOD OF CALCULATING PAVEMENT STRESSES DEVELOPED BY SUBGRADE RESISTANCE ILLUSTRATED

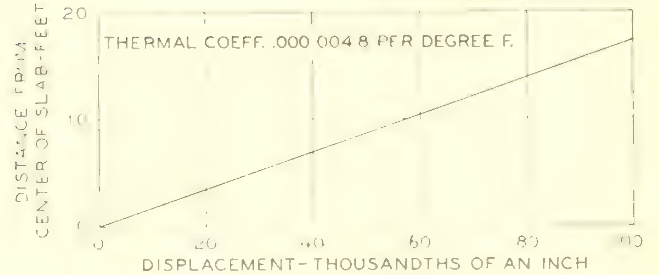
It will be apparent from the data and discussion which have been presented that, in any consideration of pavement stresses developed by this subgrade resistance, account should be taken of the extent of the displacement of each part of the slab. A suggested method for utilizing the data for this purpose is outlined in the following example:

In figure 22A the force-displacement curve for the 6-inch slab is repeated from figure 20. In this figure the vertical scale applies to a unit area of one square foot. This scale was chosen simply as a matter of convenience for use in the example. In figure 22B is a curve showing the displacement, resulting from thermal expansion, of the various parts of the slab with respect to its center point, based on the measured thermal coefficient of the concrete and a temperature change of 100° F. Inasmuch as the observed average temperature of the test pavement underwent an annual change of only 75° F., this figure may be too high but it serves the purpose of illustration as well as a lower one.

After having determined the forces necessary to move the unit slab through various displacements and having determined the displacements to which the



A - FORCE - DISPLACEMENT RELATION FOR A 6 - INCH SLAB OF UNIT AREA



B - DISPLACEMENT AT VARIOUS DISTANCES FROM SLAB CENTER DUE TO A TEMPERATURE CHANGE OF 100° F.

Figure 22.—Relations Between Displacement and Thrusting Force, and Between Displacement and Distance from Center of Slab, for Concrete Pavement Slabs.

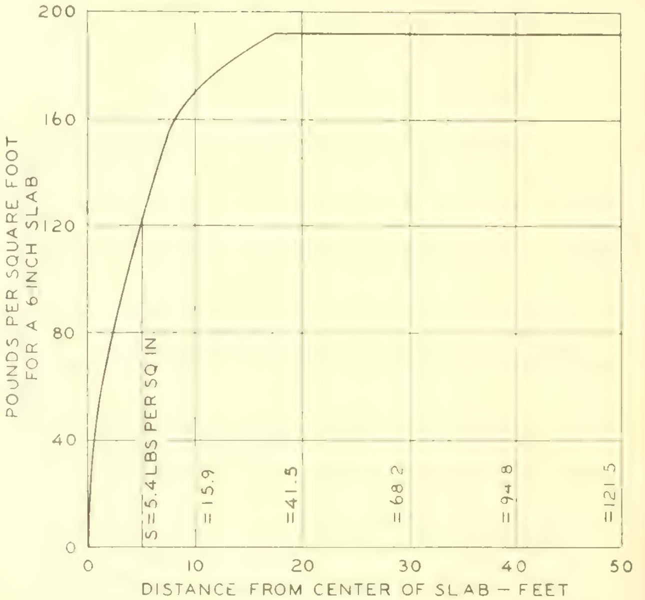


Figure 23.—Variations in Force Needed to Move Unit Areas at Various Points Along the Pavement Slab. The Resultant Stresses are Shown at Intervals.

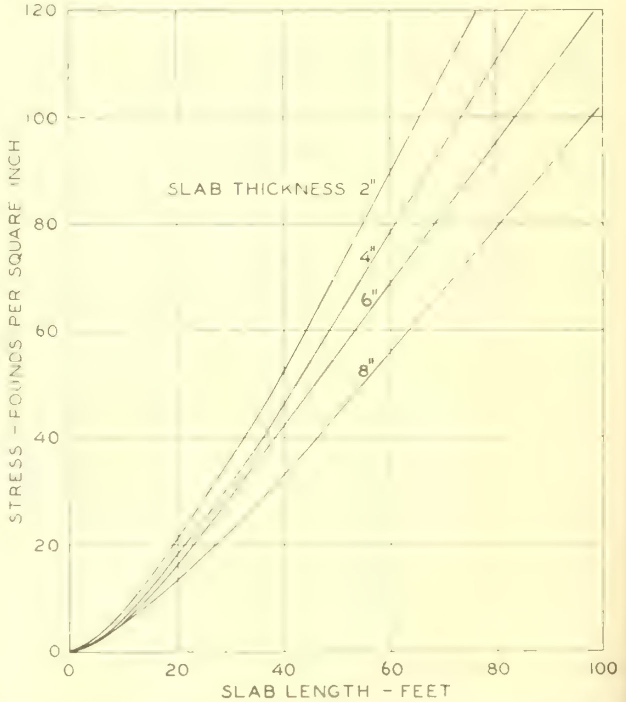


Figure 24.—Effect of Slab Length and Slab Weight on the Stresses Caused by Expansion or Contraction Resulting from a Temperature Change of 100° F.

various unit areas of the pavement may be moved by thermal expansion, the next step is to combine these data on the basis of equal displacements in order to determine the forces of resistance effective at each point throughout the length of the slab. The procedure is as follows:

Assuming a strip of pavement 1 foot in width and of appreciable length, consideration was given to successive sections 1 foot apart beginning at the mid-section of the strip (the section at which no displacement occurs during expansion and contraction). From figure 22B the displacement to be expected at each of the successive sections, caused by the assumed change in temperature, was determined. Then for each displacement the corresponding thrusting force was obtained for each section from the data given in figure 22A. The values of force developed in this way and plotted at the proper distances from the center of the slab determine the curve shown in figure 23. The total force necessary to move a strip of pavement of any given length may be determined from the area under the curve in this figure. The unit stress values to be expected are shown at intervals along the diagram, at the points where they apply.

The stresses caused by subgrade resistance were computed in this manner for the several slab thicknesses from the force-displacement curves shown in figure 20 and the resulting stress distribution diagrams are given in figure 24. These diagrams are applicable only to the particular subgrade conditions that obtained in these tests. It will be observed that the unit stresses developed by the large temperature change that was assumed for the example are small for all moderate slab lengths and also that the unit stresses for a given slab length decrease with increase in slab thickness, in accordance with the theory of subgrade resistance previously discussed.

It is interesting to compare the unit stresses obtained in the above analysis with those which would be obtained by assuming that all of the subgrade resistance developed as the result of simple sliding friction. Referring back to figure 20, it is found that for the 6-inch slab the thrust required to cause sliding was about 250 percent of the slab weight. In other words, a coefficient of friction of 2.5 might be assumed to apply. For a 6-inch slab 50 feet in length the application of this flat coefficient indicates a maximum unit stress of 62.5 pounds. This compares with a unit stress of 56 pounds by the more exact method. The difference is small but it should be remembered that this difference is caused by the elastic action of the soil and will, therefore, vary with the type and condition of the subgrade.

It seems probable that the stresses determined by the two methods would agree best for granular soils, and that for tenacious clays the values obtained by the assumption of a flat coefficient might be considerably in error. For slabs of average length, however, the stresses developed by this type of subgrade resistance are so small that, for average subgrade conditions, stresses computed by the simpler method are probably sufficiently accurate. In the tests at Arlington it was found that there was a tendency for the resistance to horizontal slab displacement to increase as the moisture content of the subgrade increased. Since the coefficient values given in the preceding tabulation were based upon data obtained at a time when the moisture content of the soil was high, it is probable that the values given approximate a maximum for the subgrade in question.

During the period of the observations there was no extended period during which the soil beneath the concrete was frozen, and it was not possible to make a study of the effect of a frozen subgrade upon the stresses being discussed. Temperature measurements in the concrete and subgrade and measurements of length changes during periods of cold weather showed that the changes in average concrete temperature at these times were relatively small. The daily air temperature range is much smaller in winter than in summer because of the decreased intensity of the sunlight. It seems quite possible, therefore, that even if the subgrade is frozen to the slab, the thermal changes in the pavement during such periods will be so small that the stresses in the pavement will not be increased to any important degree by the frozen subgrade.

TEMPERATURE WARPING DISCUSSED

Some difficulty was experienced in determining the shape of a warped slab, as approximately 1½ hours were required to make a complete set of clinometer measurements, and the temperature conditions that produced the warping rarely held constant for this length of time. This was especially true in the early morning when the maximum upward movement at the edges occurred. The data of most value are those made on days when, during the period of the actual measurement, the least change in temperature differential occurred. The occasions were rare when practically constant temperature conditions prevailed during the periods of measurement of both the flat and warped slab. Some measurements were obtained under these conditions, however, and it is believed that these data show very well the shape of the warped surface and the relative movements of its various parts.

Figures 25 and 26 show data obtained on one panel of each of the 6- and 9-inch uniform-thickness sections, respectively, and figure 27 shows similar data from one panel of the 9–7–9 thickened-edge section.

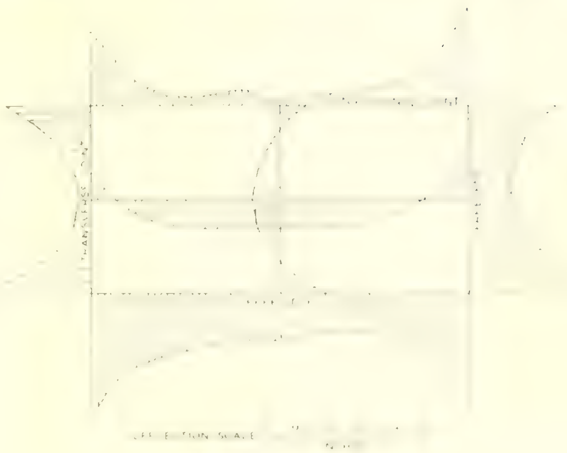


FIGURE 25.—DEFLECTIONS CAUSED BY TEMPERATURE WARPING OF A 10-BY-20-FOOT PANEL OF A 6-INCH UNIFORM-THICKNESS PAVEMENT FROM A 22° F. TEMPERATURE DIFFERENTIAL. ON APRIL 20, 1931: SLAB FLAT AT 8:30 P. M.; EDGES WARPED DOWN AT 1:30 P. M.

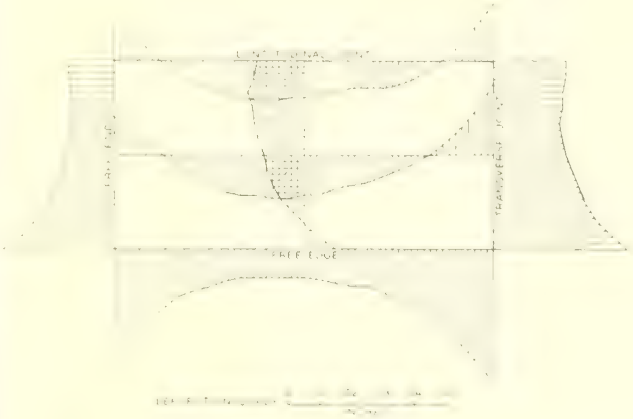


FIGURE 26.—DEFLECTIONS CAUSED BY TEMPERATURE WARPING OF A 10- BY 20-FOOT PANEL OF A 9-INCH UNIFORM-THICKNESS PAVEMENT FROM A 23° F. TEMPERATURE DIFFERENTIAL. ON APRIL 8, 1931; SLAB FLAT AT 10:30 P. M.; EDGES WARPED DOWN AT 2:30 P. M.

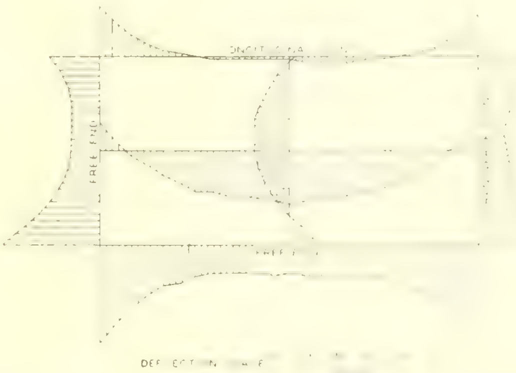


FIGURE 27.—DEFLECTIONS CAUSED BY TEMPERATURE WARPING OF A 10- BY 20-FOOT PANEL OF A 9 7–9 PAVEMENT FROM A 20° F. TEMPERATURE DIFFERENTIAL. ON APRIL 9, 1931; SLAB FLAT AT 9:30 P. M.; EDGES WARPED DOWN AT 2 P. M.

The restraining influence of the attachment to other panels at the longitudinal and transverse joints is evident in all of these diagrams. In the 9-inch uniform-thickness section the longitudinal joint is of the weakened-plane type. At the time of the warping measurements this plane had not cracked, with the result that the section acted almost as a full 20-foot-width slab. The formed groove in the upper surface of the pavement undoubtedly had some effect on the shape of the warped cross section even though the concrete below it had not cracked.

It will be noted that there are slight discrepancies in the deflections recorded at the common corner points when the measurements were made along the different edges of the panel. These are caused by the slight changes in the temperature differential during the period of the measurements.

All of the observations were made during the month of April when there is probably as much warping as at any time during the year, and the data shown are for the condition of downward movement of the edges. The data for the different sections are not directly comparable because there were some small differences in the differential at the time the various measurements were made, as noted on the diagrams.

These diagrams convey a very clear picture of the movements that occur daily in all concrete pavement slabs. In the transverse direction the panels appear to warp quite freely (except in the case of the unbroken longitudinal joint mentioned above). In the longitudinal direction the tendency for the weight of the slab to force the central area to lie flat is evident, being most noticeable if a comparison is made of the central portion of the longitudinal axes in the diagrams for the 6- and 9-inch sections shown in figures 25 and 26, respectively. This is as would be expected since the curvature should be some function of the ratio of length to thickness. The effect of this restraint on the stresses caused by warping will be apparent in data that are presented later.

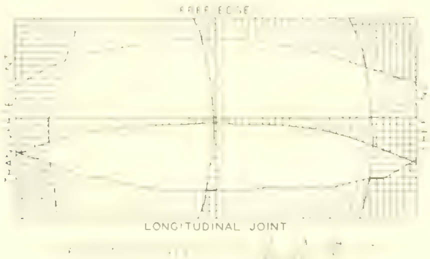


Figure 28.—Deflections Caused by Temperature Warping of a 10- by 20-foot Panel of a 9–6.3–9 Pavement from a 5° F. Temperature Differential. (American Association of State Highway Officials Cross Section). On May 27–28, 1931; Slab Flat at 8 p. m.; Edges Warped up at 5 a. m.

Figure 28 shows data obtained from a thickened-edge section of a different type at a time when the upper surface was at a lower temperature than the lower surface, with a consequent upward movement of the edges. As would be expected from the data on temperature differentials previously presented, the magnitude of the warping in this direction is always much less, since the temperature differential is less than that which occurs when the temperature conditions are reversed. The relation between the magnitude of the temperature differentials and that of the edge movements in the two directions is not a direct one.

In figures 25, 26, and 27 the downward edge movement shown was caused by differentials of about 20° F. The upward movement shown in figure 28, which is about half of that shown in the preceding three figures, is the result of a temperature differential of only 5° F. If the warping diagrams are examined it will be observed that the interior of the panel was actually raised above the flat position as the edges warped downward but that there is little or no depression of the central area as the edges are warped upward. It seems quite probable that the redistribution of subgrade reactions which must attend these changes in shape would account for the difference in the freedom of warping in the two directions that has been noted.

Figure 29.—Measuring the Pressure Between the Pavement Slab and the Subgrade.

RELATIONS BETWEEN TEMPERATURE WARPING AND SUBGRADE PRESSURE DETERMINED

Some data on the variation in intensity of subgrade pressure resulting from temperature warping were obtained with the pressure cells before the installation ceased functioning. The pressures were measured at several points across the transverse axis of one panel of the 9-inch uniform-thickness section (see fig. 29). The weakened-plane longitudinal joint in this section had not broken at the time and the slab was acting practically as one of a full 20-foot width.

Figure 30 shows the measured unit pressures at five different times during the day. The relation between the warping of the slab and the distribution of reactions is readily apparent. In the morning with the edges of the slab warped upward, the greatest pressure measured was in the interior, the pressure toward the edge being at its minimum at this time. During the day, as the upper surface of the slab expands there is a complete relief of the high pressure in the interior region and a development of a maximum reaction near the edge, exceeding the maximum previously developed in the interior by at least 50 percent.

Both the warping data and the subgrade pressure data suggest the possibility of an actual lifting of the central area from the subgrade as the edges warp downward. While it is possible that this may actually occur, it seems more probable that the vertical movements measured were all within the range of elasti deformation of this particular subgrade soil. Sub

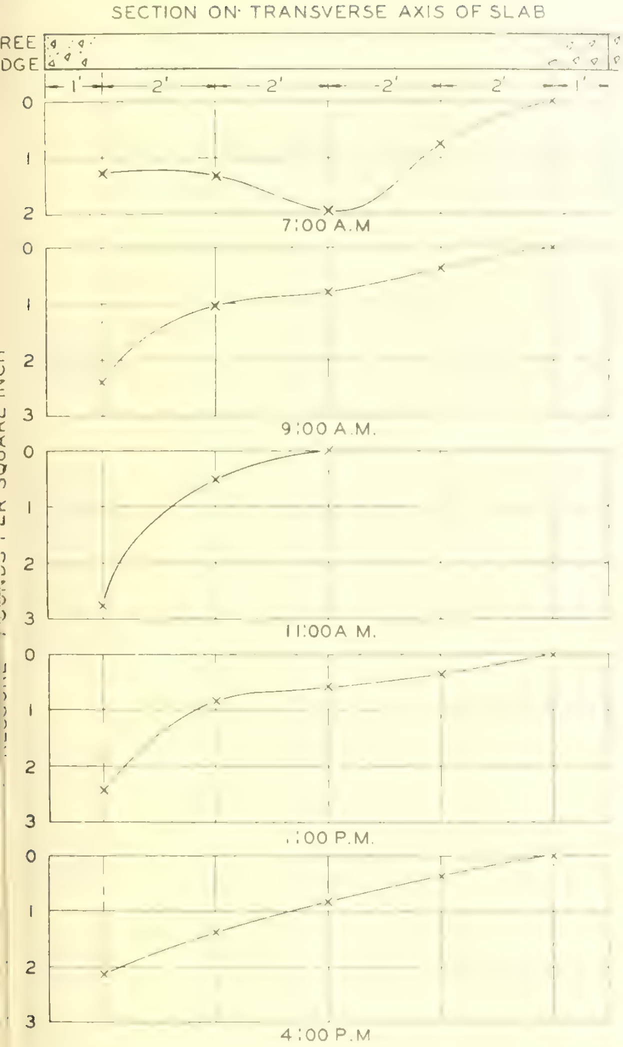


FIGURE 30.—EFFECT OF WARPING UPON THE PRESSURE OF THE SLAB AGAINST THE SUBGRADE FOR A 9-INCH SLAB.

grade bearing tests indicate that the changes of unit pressure shown by the pressure cells might be expected to cause soil deformations approximating in magnitude the vertical movements of the interior of the slab during the daily cycle of warping.

The daily variations in shape of the transverse sections of a pavement slab are well illustrated by the data in figure 31. These data furnish additional evidence on the relative magnitude of the upward and downward temperature warping and show that the maximum warping occurs during the warmest part of he day. Measurements taken at many different imes throughout the year show this to be true for all normal days irrespective of the season. This is as would be expected in view of the temperature data hat have been obtained.

The daily movements of certain points at the edges of some of the sections measured with micrometer dials are presented in figures 32 and 33. The object of he measurements shown in figure 32 was to compare he movements of sections having different thicknesses and cross sections under exactly the same conditions of air temperature variation. The vertical movement of the corner of a 9-inch uniform-thickness section is 50 percent of that of one 6 inches thick. In other

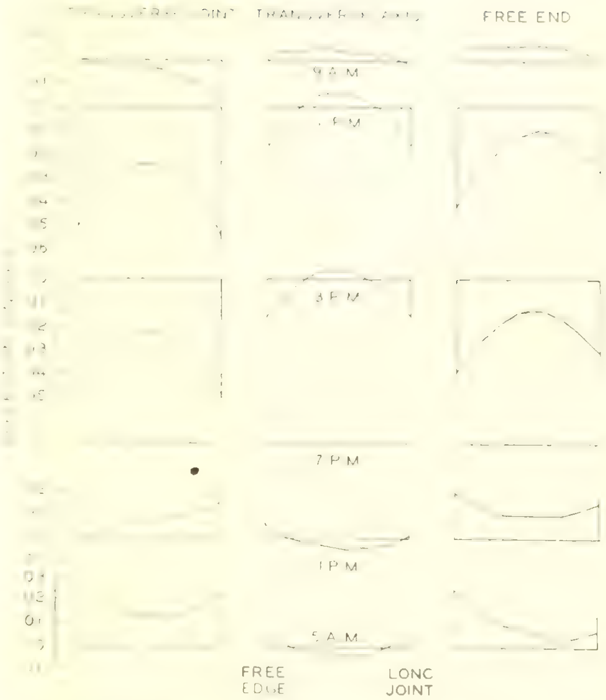


FIGURE 31.—WARPING OF TRANSVERSE ELEMENTS OF 6-INCH UNIFORM-THICKNESS SECTION. MAY 27–28, 1931.

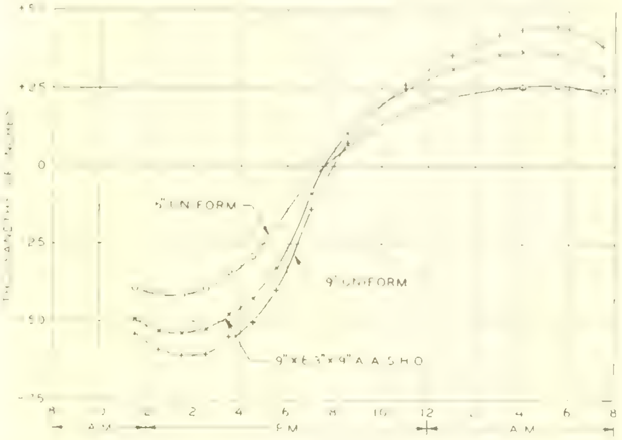


FIGURE 32.—WARPING OF CORNERS OF THREE TEST SECTIONS, MAY 27–28, 1931.

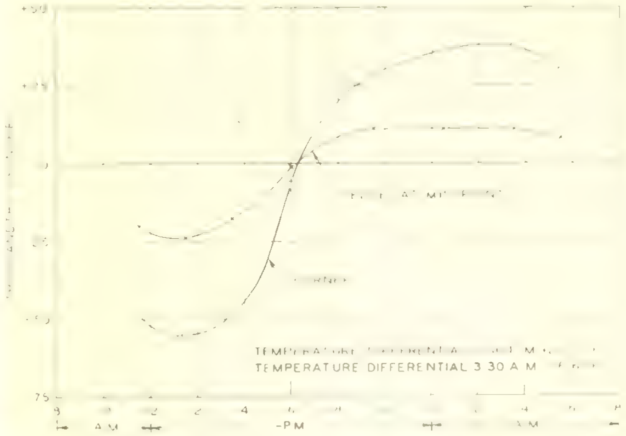


FIGURE 33.—WARPING OF EDGE AND CORNER OF 6-INCH UNIFORM THICKNESS SLAB, JUNE 8–9, 1932.

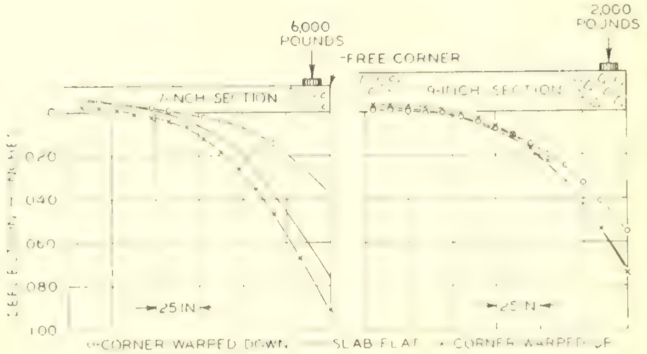


FIGURE 34.—EFFECT OF TEMPERATURE WARPING ON THE CORNER DEFLECTIONS CAUSED BY AN APPLIED LOAD (DEFLECTIONS MEASURED ALONG THE DIAGONAL).

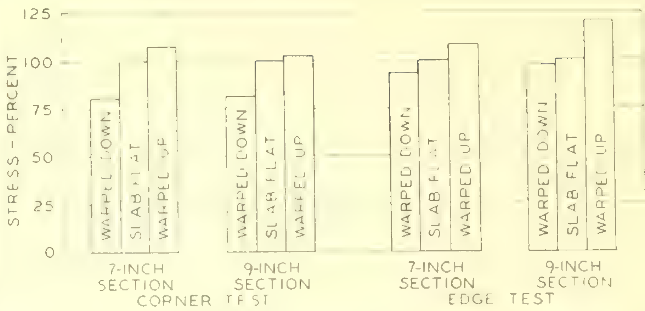


FIGURE 35.—EFFECT OF TEMPERATURE WARPING ON TE MAGNITUDE OF THE STRESS CAUSED BY AN APPLIED LOAD.

words, direct proportionality apparently exists between the thickness of the section and the magnitude of the corner movement.

Another important indication is that the 9-inch edge of a typical thickened-edge section does not cause warping movements as great as would be found in a section that was uniformly 9 inches thick. In figure 33 the vertical movements of the free corner and the mid-point of the free edge are compared. The maximum temperature differentials observed during this series of observations are noted in the figure and it is of interest to compare these with the vertical movements that they produce at the two points at which the measurements were made. The temperature differential that caused the upward movement of the edges and corners is approximately 30 percent of that which caused downward movement, yet at the corner the upward movement is 70 percent and at the mid-point of the free edge 46 percent of the downward movement. These relations are in general accord with the data previously presented in connection with the discussion of the warping data for the entire slab panel.

EFFECT OF APPLIED LOADS ON WARPED PAVEMENTS INVESTIGATED

It is logical that any redistribution of subgrade reactions, such as those occurring when a pavement warps, must result in a change in the deflections and the stresses that will be produced by a given applied load. As mentioned earlier in the discussion of the investigation, a study was made of the effect of slab shape on the deflections and stresses caused by applied loads. Figure 34 shows the elastic curves of the diagonal at the slab corner under the applied loads noted, for three conditions of warping as they occurred during a single 24-hour period. It is apparent from these curves that the 7-inch slab is affected to a greater degree than the 9-inch slab. Downward warping of the corner reduced the deflection resulting from load by about 50 percent for the 7-inch section and only 25 percent for the 9-inch section. It is believed that this difference is due to the fact that the thinner the slab the more dependent it is on the conditions of local subgrade support.

The data indicate that upward warping has but little effect on the extent of the corner deflection produced by a given load. In the case of the 9-inch slab there is no increase, while for the 7-inch section a slight increase is noted. This condition could be caused by the lack of complete contact with the subgrade with the slab in the flat position, a condition which might easily obtain at the corner of a pavement slab. Con plete contact would then be developed only by downward deflection of the corner.

Some idea of the effect of the condition of warping o the magnitude of the stress that a given load will caus may be had from figure 35. This chart shows the vari tions in the critical stresses at the corner and edge two of the sections, referred to the stress produced b the given load on the unwarped slabs as a base. Thes data were obtained at the same time and under th same conditions as the deflection data given in th preceding figure.

There is a reduction of approximately 20 percent i the critical stress for the corner loading when the corn is warped downward. Since the maximum workin stress was about 300 pounds per square inch, th reduction amounted to approximately 60 pounds pe square inch. There is also a slight increase in th critical stress if the load is applied at a time when th corner is warped upward.

For loads applied at the edges, it appears that dow ward warping results in but a slight reduction in th stress produced by a load while upward warping wi cause increases that may amount to as much as 2 percent.

Reference to the figures which show the shape of th warped panel suggests a reason for the effects that hav just been noted. When the temperature condition are such that the edges of the pavement warp dow ward, the longitudinal curvature of the panel is suc that the mid-point of the edge tends to move upwar at the same time that the transverse curvature forcing it downward. The result is that this point is no displaced downward to nearly the same degree as the corner of the slab. So far as subgrade support concerned the situation is probably but little bett than it is for the flat slab condition.

Similar tests were made at the interior of both th 7-inch and 9-inch slabs and it was found that at th point the condition of slab warping has a negligib effect upon the magnitude of the critical stress produce by a given applied load.

These tests have shown quite definitely that eve extreme conditions of temperature warping produ variations in the critical stresses caused by applie loads that are considerably smaller than has bee generally supposed.

MOISTURE WARPING DISCUSSED

As stated earlier, clinometer measurements c certain critical regions of the 9-inch constant-thickne slab were made periodically over the year at times whe no temperature differential could be detected in th concrete. The curves obtained from these measur

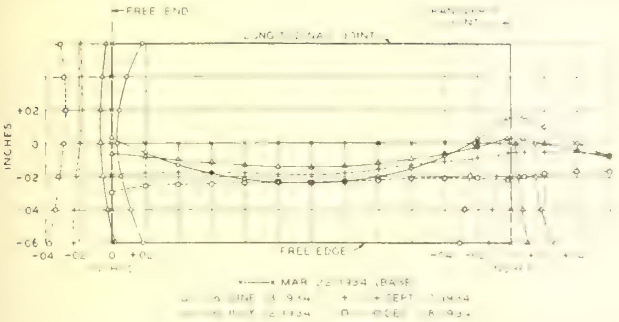


FIGURE 36.—VARIATION IN SLAB SHAPE AT VARIOUS TIMES DURING THE YEAR FROM CAUSES OTHER THAN TEMPERATURE CHANGES, 9-INCH SECTION. UPWARD MOVEMENTS SHOWN AS POSITIVE, AND DOWNWARD MOVEMENTS SHOWN AS NEGATIVE.

ments show the variation in shape of certain parts of the pavement slab at various times during the year from causes other than temperature changes.

Figure 36 shows typical data obtained from these observations of the 9-inch section. While actually a considerable number of sets of such data were obtained, in the figure only a few sets are shown for the sake of clarity. Since no means was available for determining the moisture gradient of the slab, it was not possible to predict with certainty the time when moisture conditions would be such as to cause it to be in a flat condition. In the presentation of the data in figure 36 the slab was assumed to be flat at the time of the March 22 observation on the basis of reasoning that follows.

The measurements of longitudinal expansion and contraction shown in figure 14 indicated that the expansion from moisture reaches a maximum during the winter months (January to March). For the year during which the moisture warping measurements were made (1934), the observed expansion was a maximum in January and by March it had dropped off slightly. This is a period during which the subgrade moisture content reaches a maximum value and during which the rate of evaporation is very low. It seems logical to conclude, therefore, that the moisture content of the concrete would be both high and most nearly constant during these months and that the moisture gradient that causes warping would be a minimum.

If a comparison is made between the curves in figure 36 showing the shape of the longitiudinal center line on March 22 and on December 18, it will be noted that on hese dates the shapes are essentially the same, although ome vertical movement of the slab as a whole had ccurred. This tends to substantiate a conclusion that he slab is warped but little by moisture during the midwinter months. However, it should be remembered that the data shown in figure 36 are referred to he March observations as a base and that the curves ndicate the changes in slab shape that occurred between March 22 and the other dates listed in the figure. If he slab was in an unwarped condition at the time of the March measurements, as was assumed, obviously the urves in this figure would indicate the true upward nd downward warping of the slab.

Figure 37 shows the effect of moisture on the warping f a free corner and on the vertical displacement of the nid-point of one of the 10- by 20-foot panels, over a eriod of approximately 1 year. This graph was contructed from the same data and based upon the same easurements as the previous figure, although more observations were included. In determining the warping at the free corner, it was necessary to make corrections for any vertical displacements of the slab as a whole, as well as for any tilting of the slab that might have occurred. In making the first correction, it was assumed that the vertical displacement of the geometrical center of the panel with respect to the bench mark or reference point at the edge of the slab represented fairly the vertical displacement that took place over the slab as a whole. The correction for tilting was determined by averaging the displacements of three corners of the panel to establish a plane for each observation.

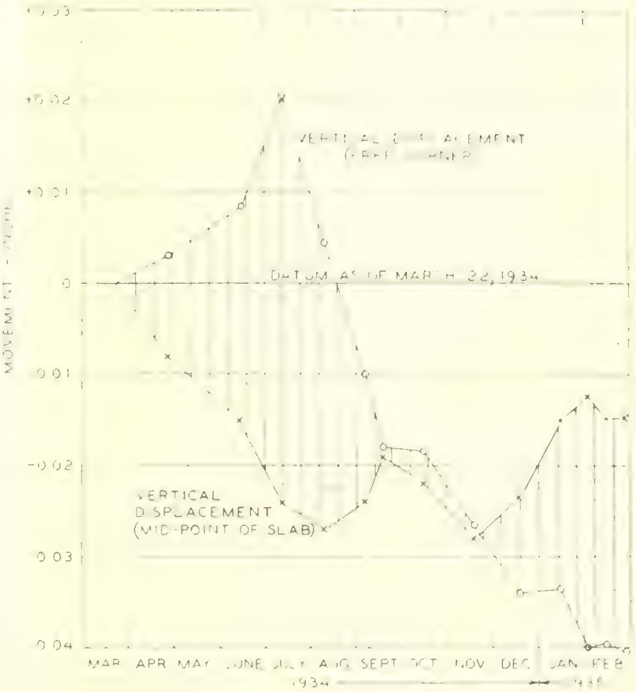


FIGURE 37.—SEASONAL VARIATION OF WARPING CAUSED BY MOISTURE CHANGE, 10- BY 20-FOOT PANEL OF 9-INCH THICKNESS. THE DISTANCE BETWEEN CURVES (SHADED AREA) SHOWS THE EXTENT OF MOISTURE WARPING.

Referring to figure 37, it will be noted that after the middle of July a sudden reversal in the direction of the moisture warping occurred. This is believed to be caused by a marked change in weather conditions that took place at about this time. During August and September of this particular year the precipitation was much above normal (over 17 inches for September alone) and there was an unusually high percentage of hazy and cloudy weather. Normally it would be expected that this change in the direction of moisture warping would occur later, possibly in late August or early September. In this connection it is interesting to compare the relation between moisture warping and time, as shown in this graph, with that between moisture expansion and time as shown in figure 14 and to note the close correlation that exists.

DIFFICULTY ENCOUNTERED IN DETERMINING STRESSES CAUSED BY MOISTURE WARPING

It will be observed from the graph that during July the loss of moisture from the upper surface had caused the free corner to be warped upward approximately 0.045 inch with respect to the mid-point of the panel. From this, an estimate of the stress developed by moisture warping might be attempted, but this is not warranted for the following reasons:

1. The true shape of the warped slab was not determined.
2. Plastic flow undoubtedly enters as a factor and its importance is unknown.
3. Settlement of the slab into the subgrade alters the degree of restraint that exists.

The curve showing the movement of the center of the panel indicates that, as the seasonal warping takes place, the slab settles into the subgrade. This seems probable when one considers that the condition of warping from moisture change develops slowly over a long period of time and that the development is most active during the spring months when the soil of the subgrade contains a considerable amount of moisture. If this is the case, it probably has an important influence upon the amount of restraint that the slab encounters when it warps from moisture changes. If there were complete settlement of the slab into the subgrade so that the subgrade conformed completely to the warped shape, then both edges and interior would have full subgrade support and no restraint would be developed by the weight of the slab.

The extent to which the subgrade adapts itself to the slab as moisture warping develops is no doubt largely dependent upon the type and physical condition of the subgrade material, but it is reasonable to believe that, because of the time element and its effect on both subgrade behavior and on plastic yielding of the concrete itself, the restraint and therefore the stresses developed by moisture warping are not as great as the magnitude of the curvature might lead one to suspect.

The data indicate that the curvature caused by moisture is principally an upward warping of the edges caused by a moisture loss from the upper surface of the pavement. The downward warping of the edges, resulting from a condition in which the moisture content in the upper part of the pavement exceeds that in the lower part, seems to be considerably smaller for the conditions of these tests.

Thus it appears from the data that, at those times when high stresses are developed by temperature warping, as for example, an afternoon in midsummer, the effect of moisture is to cause curvature such that any stresses developed by it will tend to relieve rather than aggravate the stresses caused by the restraint to temperature warping.

STRESSES CAUSED BY RESTRAINED TEMPERATURE WARPING DETERMINED

It is believed that one of the most important results of the entire investigation has been the development for the first time of reasonably reliable experimental data showing the magnitude and distribution of the stresses caused by the restrained temperature warping of typical pavement sections. These data, obtained by the methods that were described at the beginning of this paper, are presented in various ways in the figures that follow.

It has been shown that under normal conditions the temperature differential that causes warping is much larger during the day than during the night, and that usually the daily maximum occurs in the early afternoon. Since it was desired principally to determine the magnitude of the warping stresses for the condition of average maximum temperature differential, the greater portion of the measurements were made during the daytime with the upper surface of th pavement at a higher temperature than the lowe surface. The warping stresses occurring under th condition are more important also because tension developed in the bottom of the slab. A sufficier number of night observations was made, however, t give a clear indication of the magnitude and relativ importance of stresses developed at night.

The manner in which the stresses produced b restrained temperature warping during the day var along the two principal axes of two of the test sectio panels is indicated by the curves in figures 38 and 3 The data in figure 38 apply to the transverse axe while those in figure 39 apply to the longitudinal axe of the two slabs. At each point along each axis th stresses in both the transverse and longitudinal dire tions were determined. The values shown in thes figures are averages of several sets of measuremen made on selected days during the summer and fall.

The data pertaining to the transverse axis were a obtained during the summer but some of those pe taining to the longitudinal axis were obtained durin the fall when the temperature differentials were n as large as during the summer. The values show in figure 38 probably represent the largest that wi occur with any frequency in the locality where th tests were made. The maximum values observe at any time were approximately 15 percent great than the averages shown in this figure.

During a part of the tests the slabs used for th temperature measurements were unavoidably shade so that complete data on the temperature differentia causing these stresses are not available. From th temperature data obtained it is estimated that th average temperature differentials causing the stress shown in figure 38 were approximately 18° F. for th 6-inch and 23° F. for the 9-inch test sections.

In the absence of data on sections less than 20 fe in length, it is not possible to predict accurately wha the maximum warping stresses on shorter sectio would be. However, up to the present time very fe concrete pavements have been laid in which the lengt of the slab units was less than 20 feet. For slab lengt greater than 20 feet, it is believed the data indicat that, for a 6-inch slab thickness, the maximum war ing stress will not exceed that developed in the 20-fo slab, while in a 9-inch pavement the maximum war ing stress may be somewhat greater than that show These conclusions are based on the shape of the long tudinal axis of the two warped slabs as determine with the clinometer.

The relative magnitudes of the stresses from r strained temperature warping at several points ne the corners of the 6-inch and 9-inch uniform thickne sections are shown by the stress diagrams in figure 4 The stresses were determined along the lines A— A—C, and A—D of figure 6. Along the free edges the slab the stress in the direction perpendicular to t edge is in all cases negligible and, for this reason, on stresses in the direction parallel to the edge are sho for the lines A—B and A—D (fig. 6). Along the dia onal at the free corner (line A—C, fig. 6), measura stresses are found in both directions and the stress perpendicular to and parallel to the diagonal are sho in figure 40.

It is interesting to note that the variation in t magnitude of the stresses measured perpendicular the diagonal is similar to that of the stresses in t direction parallel to the diagonal. There seems to

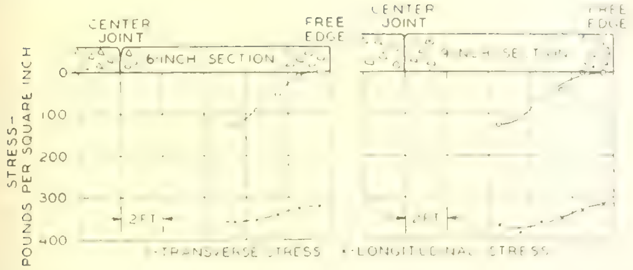


FIGURE 38.—MEASURED WARPING STRESSES CAUSED BY RESTRAINED TEMPERATURE WARPING ALONG THE TRANSVERSE AXIS OF TWO TEST SECTION PANELS.

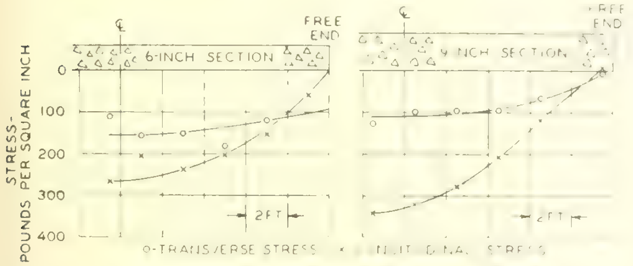


FIGURE 39.—MEASURED WARPING STRESSES CAUSED BY RESTRAINED TEMPERATURE WARPING ALONG THE LONGITUDINAL AXIS OF TWO TEST SECTION PANELS.

a consistent lack of uniformity in the variation in stress along the diagonal that might reasonably be attributed to a buckling action across the corner as this portion of the slab attempts to respond to two conflicting sets of forces.

The maximum stress along the free edge as shown in figure 40 is smaller than that shown in figure 38. This s because the stresses at the corner were determined or somewhat smaller temperature differentials.

Figure 41 shows stresses caused by restrained emperature warping at the corner and along the ongitudinal axis of the 6-inch constant-thickness section under normal night conditions, i. e., with the upper urface at a lower temperature than the lower surface. The stress values shown are the averages of several sets of observations made on nights when, for night condiions, relatively large temperature differentials devel-oped. The observations were made on 3 of the 4 panels f the test section.

It will be observed that the stresses vary in much he same manner as was found in the daytime measurenents, although their magnitude is but about oneourth as great. This is as would be expected as the bserved temperature differentials were in approxinately the same ratio. Under night conditions, the resses developed are tensile stresses in the upper urface and compressive stresses in the lower surface of e pavement. They are, therefore, opposite in sense the stresses caused by applied loads except for the se of a load applied on the corner of the slab.

STRESSES GREATEST IN LONGITUDINAL DIRECTION

In order to present a general picture of the critical ress conditions that result from restrained temperature arping, the stress diagrams shown in figures 42 to 45, clusive, were prepared, utilizing the average measred stress curves to determine the shape of the variaon curves and adjusting the stress magnitudes to a mmon value at the interior points of the slab. gures 42 and 43 show the stresses parallel to the gitudinal axes of the slabs except at the diagonal at the free corner where the stresses are parallel to the diagonal. Figures 44 and 45 are similar diagrams for the stresses perpendicular to the longitudinal axes or perpendicular to the diagonal.

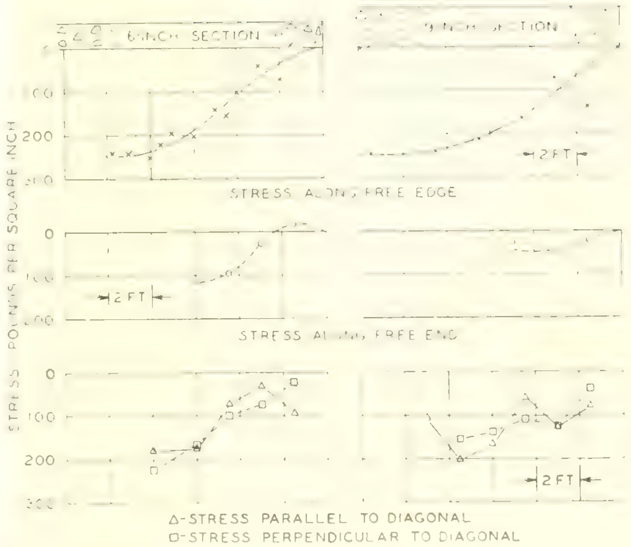


FIGURE 40.—MEASURED WARPING STRESSES CAUSED BY RESTRAINED TEMPERATURE WARPING NEAR THE SLAB CORNERS.

It was found by numerous measurements that stresses of the magnitudes indicated in these 4 diagrams may be expected to occur frequently in the daytime during the spring and summer months in the locality of Washington, D. C. As previously stated, stresses somewhat exceeding these were found occasionally on days of extreme temperature changes.

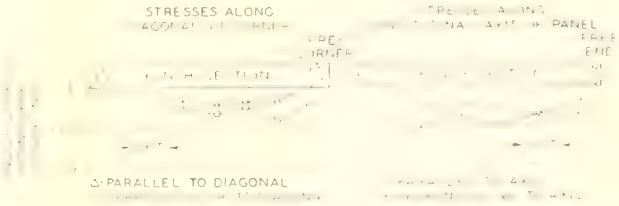


FIGURE 41.—AVERAGE MAXIMUM TENSILE STRESSES OBSERVED IN THE UPPER SURFACE OF THE 6-INCH SECTION CAUSED BY RESTRAINED TEMPERATURE WARPING AT NIGHT.

THEORETICAL AND MEASURED STRESSES COMPARED

Reference has been made to the analysis, by H. M. Westergaard, of the stresses caused by restrained temperature warping from the standpoint of theoretical mechanics. Figure 46 shows theoretical warping stresses computed for the transverse section of a slab of infinite length but finite width and utilizing elastic constants known to apply to the materials in the Arlington tests. The temperature differentials of 18° F. and 25° F. for the 6-inch and 9-inch slabs, respectively, are reasonable in the light of the temperature data obtained in this investigation. Both values are considerably higher than that assumed by Dr. Westergaard in the examples given in his analysis.

Since the Westergaard analysis is based upon the assumption of a slab of infinite length, it is perhaps not permissible to make direct comparisons between the theoretical stresses and those determined experimentally. However, since the length of the experimental slabs is twice the width, it is believed that the sections, particularly the thinner ones, will behave in a

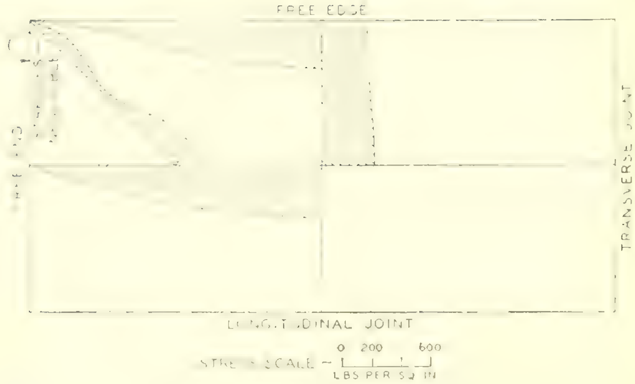


Figure 42.—Variations in Compressive Stress in the Upper Surface of 10- by 20-foot Panel of a 6-inch Pavement. Stresses Measured in a Longitudinal Direction or Parallel to Diagonal. Stresses are Caused by Restrained Temperature Warping.

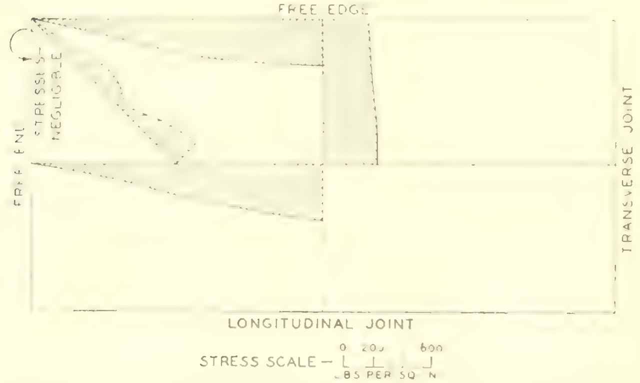


Figure 43.—Variations in Compressive Stress in the Upper Surface of 10- by 20-foot Panel of a 9-inch Pavement. Stresses Measured in a Longitudinal Direction or Parallel to Diagonal. Stresses are Caused by Restrained Temperature Warping.

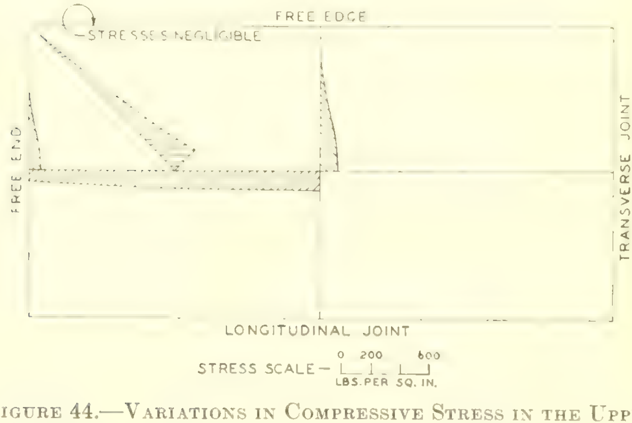


Figure 44.—Variations in Compressive Stress in the Upper Surface of 10- by 20-foot Panel of a 6-inch Pavement. Stresses Measured in a Transverse Direction or Perpendicular to Diagonal. Stresses are Caused by Restrained Temperature Warping.

manner approximating that of longer slabs, and that the stresses in a transverse section near the center are sufficiently like those in the longer slab to make a comparison with the theory of value.

If the curves in figure 46 are compared with the experimental curves shown in figure 38, it will be noted that the shapes of the theoretical and measured stress

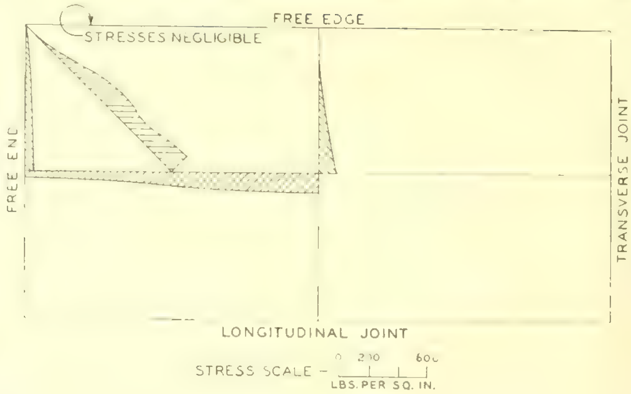


Figure 45.—Variations in Compressive Stress in the Uppe Surface of 10- by 20-foot Panel of a 9-inch Pavemen Stresses Measured in a Transverse Direction or Pe pendicular to Diagonal. Stresses are Caused by R strained Temperature Warping.

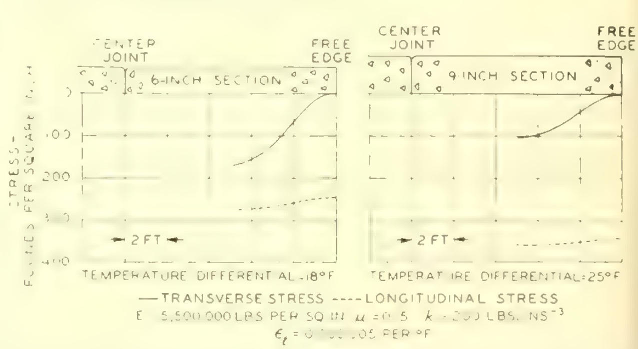


Figure 46.—Theoretical Stresses Caused by Restraine Temperature Warping at a Transverse Axis of a Sla of Infinite Length.

curves are very similar, and also that the magnitud of the theoretical stresses are of the same order as th values found by measurement. In this connection i should be pointed out again that the average temperature differentials were estimated and may not be exact From this comparison it seems reasonable to conclud that warping stresses properly calculated with th theoretical formulas will give a fair estimate of th critical warping stresses in pavement slabs 20 feet o more in length.

There is one noticeable difference, however, betwee the theoretical and measured stress relations. Th measured stresses have practically the same magnitude for both the 6-inch and 9-inch slabs in spite of the 5 F. difference in the temperature differentials. Th stresses computed by the theory, on the other han reflect this difference in higher stresses for the 9-inc thickness. It is reasonable that the greater temperature differential in the thicker slab should produc higher stresses. Had the length of the 9-inch te section been greater than 20 feet, it is believed that th measured stresses would have been higher and thu more in accord with the theory.

It has been shown previously that, when warped, th 6-inch section tends to remain flat along the centr portion of the longitudinal axis, while the 9-inch se tion showed continued curvature in this region. If th 9-inch slab had been longer it too would have bee flattened in the mid-portion of its long axis and th undoubtedly would have increased somewhat the valu of the measured stresses.

MERITS OF THICKENED-EDGE DESIGN INVESTIGATED

Data presented earlier in this paper show that when the edge thickness of a paving slab is increased, for the purpose of increasing the load-carrying capacity, there is certain to be a corresponding increase in the temperature differential that develops in this portion of the pavement. For example, it was shown that the temperature differentials observed at the edge of a 9–6–9 section were about 45 percent greater than those observed in the edge of a 6-inch constant-thickness section and approximately the same as those in the edge of a 9-inch constant-thickness section. Since an increase in the temperature differential at any part of a slab that is restrained from warping causes a corresponding increase in the warping stresses at that point, the effect just mentioned is an important consideration in the design of concrete pavements.

The effect of increasing the thickness of the edges of a pavement slab on the magnitude of the critical warping stresses can be illustrated by considering two long and relatively narrow pavement slabs both of the same interior thickness. One is of constant thickness while the other is of a conventional thickened-edge cross section with an edge depth 50 percent greater than the interior depth. The temperature differentials and therefore the warping stresses that develop in the interior of the two slabs will be approximately the same since the slabs have the same thickness in this region and are both sufficiently long to develop complete restraint. At the free edges, however, the differential in temperature for the thickened-edge cross section will be, according to the data obtained in this investigation, some 45 percent greater than in the slab of constant thickness.

The results of the increased temperature differential at the edge of the thickened-edge section will be an increase in the stresses caused by restraint to warping in the edge region of the slab. Since the slabs are relatively narrow in a transverse direction they are relatively free to warp and the warping stresses will be small. Thickening the edge will therefore have but little effect upon the transverse warping stresses. In the direction parallel to the edge of the pavement, the magnitude of the warping stresses varies with the degree of restraint that obtains at the particular point under consideration. The degree of restraint varies, in turn, with the distance from the free end of the slab and with the slab depth. At the extreme end no restraint exists as the slab can warp freely at this point. The rate at which restraint develops with the distance from the extreme end will depend upon the depth of the slab, as will the distance to the point where complete restraint is obtained.

The two slabs considered in the example were long enough to develop complete restraint and consequently maximum warping stresses in their mid-length, and in this region it was found that the temperature differential at the edge of the thickened-edge section was about 45 percent greater than in the edge of the slab having a constant thickness equal to that of the interior of the thickened-edge section. Since, theoretically, there is a direct relation between the magnitude of the stress esulting from completely restrained warping and the emperature differential that exists, this 45 percent ncrease in the temperature differential would lead one o expect a corresponding increase in the warping stress.

The relations between slab length, slab depth, and estraint to temperature warping were not determined by this investigation. To study this problem thoroughly, a range of slab lengths in each of several thicknesses would have to be constructed and the critical warping stresses determined for each. The data obtained would make it possible to determine what lengths of slab are sufficiently free to warp to make relatively unimportant the increase in warping stresses that results from the increased edge thickness. All of the slabs cast for this study of concrete pavement design were of the same length and only limited data bearing upon the relations could be obtained. These data are presented later in this paper.

WARPING STRESSES IN THICKENED-EDGE AND CONSTANT-THICKNESS SECTIONS COMPARED

Some measurements were made to determine the warping stresses at the edge of a 9–6–9 test section in comparison with those at the same point in the 6-inch and 9-inch constant-thickness sections. The data obtained are given in table 4.

TABLE 4.—*Observed longitudinal warping stresses at the edge of three 20-foot pavement slabs*

Date, 1934	Temperature differential at edge			Observed longitudinal warping stresses			Increase in stress, 9–6–9 slab over—	
	6-inch slab	9-inch slab	9–6–9 slab	6-inch slab	9-inch slab	9–6–9 slab	6-inch slab	9-inch slab
	° *F.*	° *F.*	° *F.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Percent*	*Percent*
Apr. 18	18	27	27	220		316	44	
Apr. 22	14	24	21	186		218	17	
Apr. 24	21	31	29	195		291	49	
May 9	18	25	24	209	191	245	17	28
May 18	21	30	30		298	380		28
May 19	20	26	29	252	306	380	51	24
May 20	23	33	32		302	361		20
May 21	20	31	32	320	329	409	28	24
May 22				322	252	347	8	38
May 24	19	25	25	266	213	282	6	32
June 2				229	251	336	47	34
June 3				281	273	377	34	38
Average							30	30

These data were obtained from simultaneous measurements at the mid-length of the three 20-foot test slabs—the 6-inch constant-thickness slab (sec. no. 10), the 9-inch constant-thickness slab (sec. no. 6) and the 9–6–9 thickened-edge slab (sec. no. 5). The observations extended over a considerable period of time and it is thought that in spite of some inconsistencies, the data give a very good indication of the relative magnitude of the longitudinal warping stresses in slabs of these thicknesses and this length. The temperature differentials are typical of the highest average values that may be expected to occur frequently in the locality where the tests were made.

It will be noted that the stresses measured at the edge of the 9–6–9 slab are in every instance higher than those measured at the edge of either of the constant-thickness slabs. At times this difference is as much as 100 pounds per square inch for the 6-inch and 80 pounds per square inch for the 9-inch constant-thickness slabs. The last two columns of table 4 show these differences, expressed as a percentage of the stress in the constant-thickness slab. There is a considerable variation in these values for the comparison with the 6-inch slab, the reason for which is not known.

The average increase of warping stress of the thickened-edge section over the 6-inch constant-thickness section is approximately 75 pounds per square inch, or

30 percent. The average difference in corresponding temperature differentials is 47 percent. These data indicate, therefore, that the increase in stress is not as great as might be expected in view of the measured increase in temperature differentials. This may be the result of the thickened-edge slab warping slightly more at the point where the stresses were determined than does the 6-inch slab, because of the difference in the length-depth ratio, and is thus able partially to offset the effect of the increased temperature differential. From these tests it might be concluded that the full effect of increased temperature differential resulting from the increased depth of the slab edge of this 9–6–9 cross-section does not develop in a slab length of 20 feet.

It may seem surprising that the longitudinal warping stress in the thickened-edge section is consistently greater than that in a constant-thickness slab of the same edge depth, particularly in view of the fact that the measured temperature differentials were approximately the same in the two slabs. The explanation is believed to be that in slabs of the same length the 9-inch constant-thickness slab would be expected to warp more freely than the 9–6–9 thickened-edge design.

The data resulting from loading tests that are to be presented in a subsequent report of this series show that the 50-percent increase in edge thickness of the 9–6–9 as compared with the 6-inch constant-thickness slab resulted in a reduction of approximately 28 percent in the critical stress caused by load applied at the edge of the pavement. For example, the reduction in the critical load stress effected by the thickened edge for a 7,000-pound load applied at the edge position amounted to approximately 100 pounds per square inch in these tests.

Figure 39 shows that the average warping stress at the edge of the 6-inch constant-thickness section is approximately 320 pounds per square inch during the summer. It has just been shown that the edge thickening under consideration caused an increase of approximately 30 percent in these stresses. The edge thickening, therefore, causes an increase of approximately 90 pounds per square inch, which is practically equal to the reduction in load stress accomplished by the increased edge thickness. This indicates that, on the basis of the combined load and temperature stresses, at times when the warping stresses are high, the load-carrying capacity of the 20-foot, 9–6–9 section is not increased by the edge thickening. For much shorter slabs this would not be true because the warping stresses would be low, but for slabs of greater length it is indicated that at times when the warping stresses are high, the load-carrying capacity of the edge of a pavement slab may actually be reduced by thickening the slab edge.

IMPORTANCE OF REDUCING WARPING STRESSES DISCUSSED

The data that have just been presented clearly indicate that the stresses arising from restrained temperature warping equal in importance those caused by the heaviest wheel loads. The stresses from this cause are actually large enough to cause failure in concrete of low flexural strength, and since the direction of the stresses is such that they become added to the critical stresses caused by wheel loads, there is little doubt but that warping stress is primarily responsible for much of the cracking in concrete pavements. It must be concluded also that so long as the slabs are of considerable length originally, a thickened-edge design will not reduce the amount of transverse cracking that will occur. This conclusion is in agreement with the observations made on this point in the extensive pavement survey conducted several years ago by the Highway Research Board.[13]

It is evident that either the magnitude of the warping stresses must be reduced by building smaller slab units or by some other means not yet proposed, or the amount of stress resistance available for supporting wheel loads will be greatly curtailed.

The most practical means at present available for reducing warping stresses is through the construction of shorter slabs. As previously mentioned, some data that indicate the possibilities of reducing warping stresses through a decrease in slab length were obtained in this investigation. In the first place, a comparison of the relative magnitudes of the stresses created by warping at the center of the slab in the transverse and longitudinal directions shows that the stress in the direction of the 10-foot dimension is approximately one-third of that in the 20-foot dimension.

Some other data upon this point were obtained during the spring of 1934 when a transverse crack developed at the center of one quadrant of one of the thickened-edge sections (sec. no. 4). This afforded an opportunity to measure the longitudinal warping stress in both the 10- and 20-foot lengths of the same slab and to make a comparison of their magnitudes. The longitudinal stresses were determined at two positions in the mid-lengths of each slab, at one point 6 inches from the edge and at one 5 feet from the edge (center of the panel).

The measurements were made on suitable days during the months of April, May, and June 1934, and all of the data obtained are presented in table 5.

TABLE 5.—*Observed longitudinal warping stresses in 10- and 20-foot slab lengths of sec. no. 4*

Date, 1934	Maximum air temperature	Maximum longitudinal warping stress				Reduction in stress from decreased slab length	
		Interior		Edge			
		20-foot length	10-foot length	20-foot length	10-foot length	Interior	Edge
	°F.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Percent*	*Percent*
Apr. 26	68	307	132			57	
May 1	74	376	142			62	
May 2	71			121	68		[1] 44
May 13	83	287	81			72	
May 14	90			278	21		92
May 28	83	429	151			65	
June 1	90			354	46		87
June 11	94			285	38		87
June 14	88			313	20		94
June 15	94			252	19		92
June 21	101	451	132			71	
June 22	96	414	130			69	
June 25	97			283	51		82
Average						66	89

[1] Not included in the average.

It is apparent again in these data that the longitudinal warping stress in the 10-foot slab length is consistently much smaller than the corresponding stress in the 20-foot slab. This is especially true for the stresses measured near the edges of the two slabs. The average reduction in the critical warping stress caused by the decreased slab length is approximately 66 percent in the interior of the slab and 89 percent at the point near the free edge. The greater reduction noted in the stresses near the edge of the slab may be a natural condition or it may be caused by the fact that the two 10-foot sections of the slab were restrained from free warping to a certain degree at the longitudinal joint. This restraint results from the fact that the two 10-foot lengths of this section were attached to an uncracked half of the same section by the tongue-and-groove longitudinal joint.

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[13] Economic Value of Reinforcement in Concrete Roads, by C. A. Hogentogler Proc. Fifth Annual Meeting, Highway Research Board, pt. II.

The data and discussion just presented indicate the necessity for short slab units if the stresses produced by restrained warping are to be kept within economical limits. The desirability of slab lengths of approximately 10 feet is indicated and this may, at first thought, seem to be impractical because of the number of transverse joints that would be required. One problem of joint design is to overcome the difficulty of providing satisfactorily for the movements caused by the expansion and contraction of abutting slabs. If very short slabs were used, the very frequency of the joints would largely solve this problem and thus simplify the joint design requirements.

It was shown earlier that the critical temperature-warping stresses in the corner region of a pavement slab occur during the daytime when the sense of the warping stress is opposite to that of the critical stress caused by load. During the night and early morning when the sense of the two stresses is the same, the magnitude of the warping stress is very small. It is evident, therefore, that increasing the thickness of the edge of a pavement slab will be effective in reducing the combined stresses in the corner area and consequently will reduce corner cracking. This conclusion is likewise in agreement with the observations of the survey previously referred to.

SOME EFFECTS OF FREEZING AND THAWING OF SUBGRADE DETERMINED

As mentioned previously, because of the comparatively mild winters in the region where the tests were made there was very little opportunity to study the effects that a frozen subgrade might have on the pavement sections. During the latter part of the winter of 1933–34, however, severe weather caused the subgrade under the test slabs to freeze solidly to a depth of about 2½ inches and frost crystals were found at a slightly greater depth. The earth shoulders were frozen solidly to a depth of about 7 inches and frost crystals were found at depths of 10 or 11 inches.

During this period observations were made with the linometer to determine the vertical movements that leveloped in the various parts of the slab, the technic being the same as that used in the measurements of warping. Figure 47 shows the position and shape of the 9-inch constant-thickness section on two different lays referred to its position during the preceding eptember as a base. The first series of observations Feb. 23) show the position of the slab with the subrade frozen, while those made on March 6 show its osition just after the subgrade had thawed.

These data show that, for the conditions that btained, the freezing of the subgrade lifted the entire anel almost uniformly to the extent of about one-half ich. It is interesting to note that this lift was proluced by a subgrade that was frozen solidly to a depth f only 2½ inches. As soon as the subgrade had thawed ompletely the measurements showed that the slab ttled back about three-fourths of the distance through which it had been lifted, and that during the next several days the slab was slowly settling. Traffic on the pavement would probably accelerate this settling during the period of thawing.

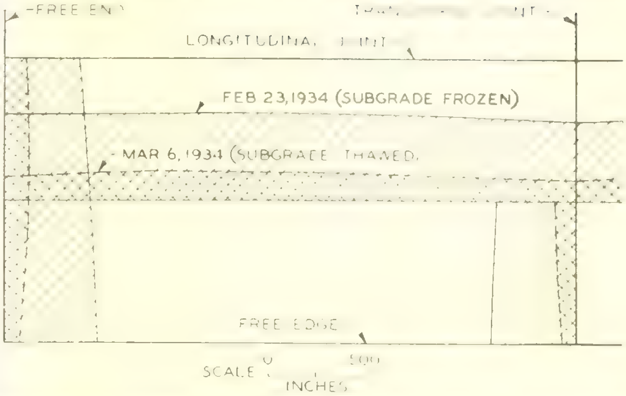

Figure 47.—Effect of Frozen Subgrade on Elevation of 9-inch Uniform-Thickness Slab, Base Elevation as of Sept. 24, 1933.

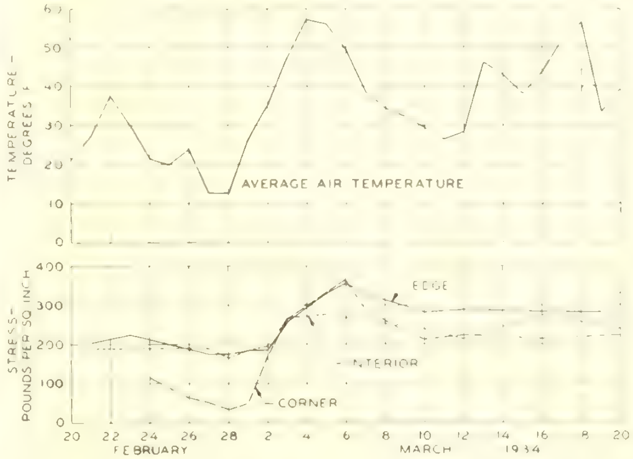

Figure 48.—Daily Variation of Stresses Caused by a 7,000-pound Load on a 9-6-9 Thickened-Edge Section, Over a Period of Freezing and Thawing of the Subgrade.

Tests were made to determine the effect of the freezing and thawing of the subgrade upon the stresses caused by applied loads. The 9–6–9 thickened-edge section was selected for this purpose and loads were applied at a free corner, at the interior, and at a point 6 inches from a free edge. The 8-inch diameter circular bearing plate was used in all cases. The tests were started during the time when the subgrade was frozen solidly and were repeated frequently until after the subgrade had thawed completely. The variations in the maximum stress produced by a 7,000-pound load applied at each of the three positions previously mentioned during the entire period are shown in figure 48, together with the variations in the average daily air temperature.

From these data it appears that the subgrade was in a fairly normal condition after March 10, or about 10 days after it first started to thaw. The subgrade was no doubt still very wet at this time, but it is known that this particular soil remains very wet during the winter even when not subjected to freezing and thawing.

It will be observed that at all three of the points tested the stresses from the applied load were reduced during the period when the soil was frozen. The effect was much greater at the corner than at the other points, probably because a much greater deflection is required to produce a given stress at this point.

As soon as thawing started there was an immediate increase in the stress at all of the points. As the subgrade became completely thawed the stresses were slightly above normal and they remained at this general level during a period of 6 or 8 days.

It is interesting to note that when the subgrade is in what may be termed its "normal" winter condition, but unfrozen, the stresses produced by a given load at the free corner and interior of this section are of approximately the same magnitude while the stress at the edge is but slightly greater.

It appears from these data that the conditions of freezing and thawing that obtained during the tests had no serious effect upon the magnitude of the stresses developed under the applied load. Had the subgrade been frozen to a greater depth or had the subgrade material not been uniform, it is possible that the effects of freezing would have been more serious.

CONCLUSIONS

In this study of the effects of temperature and of moisture on concrete pavement slabs, it has been found that in the locality where the tests were made (Washington, D. C.):

1. The average pavement temperature undergoes an annual change of about 80° F.
2. The maximum temperature differentials observed at the edges of the test sections were:
   - *a*. For a 6-inch uniform-thickness section, 23° F.
   - *b*. For a 9-inch uniform-thickness section, 33° F.
   - *c*. For a 9-6-9 thickened-edge section, 33° F.

   These maxima occur during the hot afternoons of early summer when the upper surface of the pavement is heated by the intense sunlight and the lower surface is kept cool by a subgrade that is still at a relatively low temperature.
3. In the thickened-edge design (sec. no. 5) the temperature differential in the interior of the slab averaged about 4° F. less than that at the thickened edge during the most critical part of the year.
4. There is a cyclic variation in slab length that is entirely dissociated from temperature changes. The annual variation in the length of the test sections from causes other than temperature changes is approximately equivalent to that caused by a temperature change of 30° F., and the maximum length occurs during the late winter when the ground moisture content is greatest. Conversely, the slab is shortest during the late summer when the ground moisture and, so far as could be determined, the concrete moisture are a minimum.
5. The thermal coefficient of expansion of the concrete as determined in the laboratory is 0.0000048 per degree F. This value agrees almost exactly with that determined by measurement of actual temperature expansion in the test sections, indicating: First, that the movement of a pavement slab from thermal expansion can be predicted accurately from laboratory determinations of the thermal coefficient; and second, that in slabs of moderate length the effect of subgrade restraint on slab expansion is so small as to be negligible.
6. The resistance developed in the subgrade to horizontal slab movement is not merely a matter of sliding friction in the commonly accepted sense of the word. It appears to consist of two elements, one an elastic deformation of the soil horizontally that is present for all displacements of the slab, and the other a frictional resistance that develops only after a certain amount of elastic deformation has occurred. The first element appears to be independent of, while the second varies directly with, the slab weight or thickness. Although only one subgrade material was involved in these tests, it seems probable that the relative importance of the two elements may vary considerably with different types of soils.
7. In pavement slabs of moderate length the tensile stresses resulting from contraction will not be large for subgrade soils of the type used in these tests. The thicker the pavement the lower will be the unit stress from this cause, other conditions being the same.
8. The changes in shape of a pavement slab resulting from restrained temperature warping do not cause large changes in the critical stresses from applied loads. In this investigation, the maximum observed condition of upward warping from temperature was found to increase the critical stress resulting from load by about 5 percent for a corner loading and about 20 percent for an edge loading, as compared with the stresses produced by the given load with the slab in the flat or unwarped condition. Maximum downward warping was found to effect a negligible reduction in the load stress at the edge and a reduction of about 20 percent at the corner.
9. For pavement slabs of the size used in this investigation or larger, certain of the stresses arising from restrained temperature warping are equal in importance to those produced by the heaviest of legal wheel loads. The longitudinal tensile stress in the bottom of the pavement, caused by restrained temperature warping, frequently amounts to as much as 350 pounds per square inch at certain periods of the year and the corresponding stress in the transverse direction is approximately 125 pounds per square inch. These stresses are additive to those produced by wheel loads.
10. In long or even moderately long pavement slabs, when conditions are such as to produce large temperature differentials, thickening the edge of the slab may actually decrease the load-carrying capacity of this part of the pavement. In very short pavement slabs, thickening the edge of the slab

may be expected to increase definitely its load-carrying capacity.

11. Since the critical stresses resulting from restrained warping are opposite in sense to those caused by applied loads in the corner region of a pavement, thickening the edge of the slab may be expected to increase the load-carrying capacity of the slab corner.
12. Because of the facts stated in conclusions 10 and 11, it is evident that thickening the edge of a long pavement slab will not tend to reduce transverse cracking but will tend to reduce corner cracking.
13. The annual cyclic variation in moisture conditions within the concrete produces a warping of the slab surface similar to that caused by temperature. The edges of the slab reach their maximum position of upward warping from this cause during the summer and the maximum position of downward warping during the winter, the extent of the upward movement apparently exceeding that of the downward movement considerably.
14. While sufficient information is not available to permit an estimate to be made of the magnitude of the stresses arising from restrained moisture warping, it appears that at the time of year when the stresses from restrained temperature warping are a maximum (the summer months) any stresses caused by restrained moisture warping will be of opposite sense and will thus tend to reduce rather than to increase the state of stress created by restrained temperature warping.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF OCTOBER 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 7,416,251	$ 3,664,762	$ 649,877	417.1	$ 1,495,617	$ 282,931	$ 1,040,178	62.7		$ 158,785	9.0		$ 281,082
Arizona	3,855,555	1,381,051	5,585,167	3,829,743	1,044,260	385.5	420,756	15,039	313,333	9.4		6,580	.1	$ 10,773	16,879
Arkansas	3,334,167	1,714,000	4,383,860	2,895,474	782,558	197.7	1,324,374	394,978	790,058	69.2		32,191	.1	43,716	109,194
California	7,912,928	3,713,643	12,755,782	7,790,341	1,587,165	415.9	2,683,780	121,227	1,989,200	32.4		56,779		1,360	80,499
Colorado	3,437,265	2,424,504	6,068,320	3,401,939	2,412,804	293.2	28,829	23,817	5,012					11,510	6,689
Connecticut	1,404,213	607,500	2,125,647	1,398,014	415,900	36.2	138,826		138,826	1.8				6,199	52,774
Delaware	877,566	461,697	1,355,369	877,566	456,600	48.8	1,102		1,102						3,996
Florida	2,469,369	1,110,600	4,104,035	2,422,540	830,923	155.4	132,367	29,331	94,809	1.5		173,253	1.7	16,998	17,515
Georgia	5,045,592	2,556,745	5,897,379	4,372,974	1,224,853	384.6	1,115,340	509,281	558,035	43.8	$ 15,717	136,834	8.8	147,619	637,022
Idaho	2,166,858	1,131,910	2,870,866	2,158,429	611,486	232.1	346,134		345,193	16.5		1,670	.1	8,429	173,561
Illinois	4,408,827	2,408,778	3,732,559	3,083,964	581,350	65.3	2,909,847	1,284,028	1,625,004	41.8		202,424		34,836	
Indiana	5,018,921	2,688,632	4,932,428	4,417,417	328,454	136.7	2,800,981	523,593	2,242,173	144.8		3,920		77,910	114,085
Iowa	5,027,830	1,963,361	7,385,725	4,988,630	1,896,876	439.0	108,629	39,200	65,500	.4					985
Kansas	5,044,802	2,354,131	6,861,311	5,004,394	1,679,030	711.7	715,534	31,530	661,756	49.5		13,345	.9	8,878	
Kentucky	3,751,605	1,302,209	4,417,336	3,512,268	641,962	318.8	844,702	182,976	532,648	27.6	8,570	5,000	1.1	47,790	122,599
Louisiana	2,693,135	1,380,419	3,399,544	2,481,602	390,211	86.9	784,764	34,263	750,481	18.7	141,616	227,147	14.2	35,634	12,579
Maine	1,567,012	782,195	2,169,629	1,549,427	589,812	57.5	192,303		192,289	6.8				17,585	94
Maryland	1,782,263	332,836	1,316,429	1,191,392	123,526	25.0	630,329	500,659	129,670	12.8		74,482	3.4	90,213	5,157
Massachusetts	1,101,716	1,582,874	2,127,801	1,101,653	530,306	48.2	1,022,691		1,022,691	11.4				63	29,877
Michigan	6,051,533	3,126,284	7,971,596	5,932,694	1,594,911	327.5	1,543,550	64,600	1,475,250	74.6		56,123	3.0	4,239	
Minnesota	4,561,011	2,533,733	7,177,401	4,515,018	2,371,404	1,082.5	174,714	30,000	106,779	16.2		54,971	1.1	15,993	578
Mississippi	3,489,337	2,832,182	6,146,390	2,854,077	875,755	322.7	2,566,080	570,597	1,609,119	136.6	5,574	294,586	14.2	59,089	52,722
Missouri	5,237,532	2,890,666	5,532,245	4,582,356	336,056	225.0	3,262,066	654,277	2,419,784	100.0		25,508		899	109,318
Montana	4,463,849	2,714,208	7,142,910	4,296,521	2,266,796	635.7	510,273	111,796	398,477	17.5	47,836		7.3	7,695	48,936
Nebraska	3,914,481	1,982,182	5,867,233	3,866,972	881,537	443.8	1,356,503	18,006	1,091,817	34.6		6,264		29,503	2,564
Nevada	2,909,387	1,350,356	4,264,712	2,877,829	1,239,625	464.8	85,927		73,567	39.0		1,650		31,558	35,514
New Hampshire	692,119	465,404	1,184,179	692,119	444,376	23.3	18,628		18,628	.1					2,401
New Jersey	3,173,019	951,379	3,129,342	2,793,057	146,403	46.8	1,029,469	345,862	586,834	8.7		20,970		34,100	197,171
New Mexico	2,846,648	1,070,769	4,227,210	2,691,814	1,375,407	408.9	349,999	62,413	287,586	22.7	37,087			55,334	13,777
New York	10,234,915	3,673,231	14,718,479	9,623,226	1,780,480	275.4	4,269,430	576,975	1,717,202	77.3	12,000	1,000	.2	22,714	174,549
North Carolina	4,761,147	1,930,365	6,298,184	4,175,134	939,851	753.7	915,940	231,240	667,805	51.0	74,297	256,314	4.6	280,476	66,395
North Dakota	2,902,224	1,469,483	3,979,428	2,725,292	648,124	1,345.9	214,649	54,799	95,319	42.6	84,821	218,725	48.4	37,312	507,315
Ohio	7,277,758	3,539,256	9,845,084	7,165,072	2,034,899	252.0	1,392,114	97,161	1,140,239	18.6		325,171	3.1	15,525	38,945
Oklahoma	4,608,399	2,342,590	6,324,410	4,421,227	1,592,969	383.9	831,484	181,499	646,415	25.3		28,063		5,673	75,142
Oregon	3,053,448	1,426,910	4,495,347	2,928,739	1,087,443	239.9	418,959	79,514	299,799	9.3				45,195	39,668
Pennsylvania	6,641,194	4,554,082	11,300,249	6,489,503	4,288,699	215.4	317,421	136,292	172,948	8.7	2,126	87,435	.2	13,272	5,000
Rhode Island	988,230	474,772	1,528,596	988,230	464,572	34.9	3,800		3,800			6,400			
South Carolina	2,729,583	940,954	2,956,054	2,639,674	249,246	254.1	498,984	34,290	464,694	23.8	11,220	52,612	.2	44,399	174,402
South Dakota	3,005,739	1,523,822	4,737,023	2,960,912	1,237,310	797.9	136,631	42,796	93,835	20.4		108,915	16.0	2,031	83,762
Tennessee	4,246,309	2,105,453	6,105,554	4,105,518	1,300,110	231.9	727,966	70,497	561,068	23.8	11,254	143,931	1.5	59,040	100,344
Texas	11,588,643	6,858,253	16,104,360	11,435,999	3,898,336	1,393.9	2,931,747	152,644	2,695,968	165.2		226,012	4.1		37,937
Utah	2,367,205	1,066,345	3,486,754	2,322,418	863,454	300.1	171,622	37,000	65,450	4.1		100,000	.3	7,787	37,441
Vermont	928,184	466,042	1,369,523	912,376	347,618	64.2	132,487	3,922	114,302	3.1		2,713		11,887	1,410
Virginia	3,731,207	1,916,178	5,616,215	3,519,936	1,586,137	248.7	449,588	159,398	248,609	19.5	11,386	7,213	.1	40,487	74,218
Washington	3,057,934	1,553,206	3,457,525	2,849,505	580,199	117.3	1,271,966	198,743	946,546	13.0		6,678		9,686	19,783
West Virginia	2,013,405	1,140,167	2,710,199	1,963,040	690,200	99.0	203,708	24,134	176,070	6.6		20,143	.1	26,231	253,754
Wisconsin	4,697,518	1,818,970	6,268,111	4,659,171	1,343,460	289.6	623,128	32,300	449,646	20.0		23,126		6,047	2,738
Wyoming	2,250,663	1,686,368	3,576,499	2,221,894	1,189,898	656.5	506,384	26,873	453,354	78.0		37,872		1,896	5,244
District of Columbia															
Hawaii	1,693,344	598,778	1,326,739	952,902		27.3	1,140,384	681,972	293,004	13.7	20,973	276,443	1.8	37,497	29,331
TOTALS	184,963,342	93,641,394	257,752,989	174,360,754	54,433,228	16,418.2	45,753,306	8,653,033	31,871,872	1,625.1	484,477	3,481,248	145.6	1,465,078	3,855,046

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF OCTOBER 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 2,455,651	$ 2,091,174	$ 343,359	63.7	$ 462,588	$ 255,706	$ 206,882	12.6	$ 11,886	$ 232,524	4.3	$ 31,161	$ 282,195
Arizona	756,982	289,673	746,297	622,804	86,475	15.1	374,317	133,822	161,998	.7				357	41,199
Arkansas	1,964,534	857,025	2,253,373	1,731,970	418,019	53.4	462,425	100,471	361,402	8.8	116,801	27,136	1.4	15,292	50,468
California	4,213,986	2,219,360	5,851,832	3,856,845	1,219,276	71.7	2,578,887	356,840	822,800	7.0		87,911	.7	301	89,373
Colorado	1,718,633	190,000	1,947,213	1,679,027	171,778	40.8								39,606	18,222
Connecticut	802,407	426,500	1,032,256	802,407	151,883	11.9	218,505		218,505	1.8					56,112
Delaware	460,409	230,849	560,623	460,282	91,834	9.2						42,012		127	97,002
Florida	1,459,649	501,200	1,885,653	1,441,744	146,700	21.8	313,134		283,813	3.3		9,807		17,905	60,880
Georgia	2,724,620	1,278,373	2,709,265	2,296,104	353,436	83.2	403,056	197,779	199,277	9.7	72,102	82,864	2.7	158,636	642,796
Idaho	1,197,829	321,126	1,224,303	1,150,878	27,359	21.3	284,291		283,103	3.0				46,951	10,664
Illinois	7,381,910	2,230,350	6,932,054	6,261,937	328,771	70.7	2,377,330	1,083,605	1,293,725	10.3		85,320	1.5	36,369	522,534
Indiana	4,287,050	2,248,858	4,739,959	4,049,430	511,971	82.5	1,740,546	185,901	1,554,467	23.8	51,719	80,140	2.2		102,280
Iowa	2,614,472	1,280,000	3,364,192	2,443,068	781,335	78.9	455,084	171,365	253,500	3.3				39	245,165
Kansas	2,522,401	1,432,949	3,393,422	2,473,483	751,065	53.2	670,904		670,904	3.8	48,918	10,980	1.3		
Kentucky	1,927,828	958,599	2,082,263	1,579,834	428,512	43.4	651,089	316,558	314,624	5.8	31,436	42,213	1.0		173,248
Louisiana	1,708,577	744,560	1,080,670	791,986	276,341	25.7	1,125,756	896,730	187,071	13.3	10,666	243,793	2.5	9,195	37,355
Maine	960,426	484,379	1,113,059	910,266	197,218	19.5	318,123	45,122	259,099	3.9				5,038	28,062
Maryland	891,132	452,514	434,065	422,396		3.8	1,282,700	468,736		2.2		127,791	.1		324,724
Massachusetts	5,007,199	847,600	3,236,487	3,003,788	157,851	18.5	2,556,680	1,974,333	582,347	1.5				29,078	107,402
Michigan	3,500,637	1,613,142	5,032,635	3,477,717	1,342,100	56.6	226,575	650	225,925	3.8		28,925		22,270	16,192
Minnesota	3,719,143	1,421,494	3,797,274	3,106,574	610,203	123.6	1,033,681	509,834	427,765	10.4	13,805	150,366	.6	86,929	233,161
Mississippi	1,744,669	354,022	1,484,253	1,256,645	175,525	46.3	566,651	445,452	79,162	16.3		9,950	.4	42,572	89,385
Missouri	4,019,501	919,152	3,437,441	3,187,383	159,948	60.2	1,478,440	704,456	664,992	8.0		94,212	.4	127,663	
Montana	1,115,962	113,092	1,191,712	1,083,109	66,149	42.7	5,994		5,994	.8				32,852	40,949
Nebraska	1,957,240	991,091	2,690,910	1,941,205	710,481	48.5	192,629	16,035	176,594	3.2		3,992			100,024
Nevada	500,051	100,000	539,499	473,788	56,234	10.8	67,552	26,150	41,402	.6				112	2,364
New Hampshire	740,334	242,465	853,411	668,379	181,465	18.9	46,123		46,123	.3	22,006		.5	49,949	14,877
New Jersey	3,117,921	1,809,500	3,356,687	2,983,109	207,990	24.3	1,068,330	10,297	838,485	4.5		635,875	1.0	124,515	127,149
New Mexico	1,674,158	529,506	1,844,774	1,568,055	261,203	41.9	151,695		151,695	1.1				106,103	116,609
New York	8,092,500	3,961,690	9,650,901	7,945,645	1,126,300	72.3	2,515,683	80,200	2,384,840	14.1		57,000		66,655	393,550
North Carolina	2,380,573	1,210,236	3,276,664	2,271,729	965,139	107.7	279,947	84,204	195,743	2.7		1,881		24,640	47,473
North Dakota	1,451,112	734,742	1,537,690	1,341,459	187,278	68.8	273,545	95,335	178,155	8.3	14,170	78,504	5.5	148	290,805
Ohio	4,335,686	2,359,503	5,674,168	4,284,639	859,673	74.5	1,610,360	46,452	1,438,470	10.4				4,595	61,361
Oklahoma	2,304,200	1,171,295	2,936,593	2,264,019	571,322	55.4	433,599	37,623	380,294	4.8		96,583	.9	2,558	127,096
Oregon	1,526,724	778,728	2,189,833	1,482,285	646,242	41.3	166,640		130,167	1.0	518			43,921	2,319
Pennsylvania	4,837,988	2,397,703	6,561,695	4,788,944	1,470,175	84.4	325,233	36,605	288,581	1.4		296,345	1.3	12,440	342,602
Rhode Island	512,665	285,760	650,675	508,370	140,964	8.9						144,796	1.1	4,295	
South Carolina	1,364,791	488,000	1,401,653	1,271,150	118,140	44.3	277,851	89,121	164,579	7.2	4,520				205,282
South Dakota	1,502,870	761,910	1,566,166	1,289,105	273,095	52.0	179,282	16,774	162,508	12.5	6,425	290,151	11.0	190,566	36,157
Tennessee	2,123,155	1,121,790	2,562,523	2,054,124	419,205	32.6	567,627	69,031	498,596	3.9		148,190	.8		55,799
Texas	6,642,863	1,795,000	6,650,894	5,889,378	601,556	149.6	1,684,678	488,169	1,040,319	15.4	265,316	132,119	2.6		21,007
Utah	778,826	533,173	1,221,740	647,321	449,873	31.7	240,121	130,060	82,300	2.6		1,000		1,445	
Vermont	500,509	240,611	752,805	486,227	188,069	17.5	52,541		52,542	1.6				14,232	
Virginia	1,948,780	956,021	2,843,763	1,923,878	661,722	44.0	239,173	1,453	195,952	4.3	9,099	52,687	1.4	14,349	45,559
Washington	1,977,260	776,603	2,728,581	1,974,755	732,352	47.5	6,495		6,495			1,415		2,505	36,341
West Virginia	1,342,270	570,085	1,213,156	1,139,949	28,109	19.4	669,664	198,519	441,660	8.0		31,667		3,802	68,650
Wisconsin	2,596,143	1,379,513	3,930,649	2,550,676	1,297,634	73.2	38,915	9,502	24,367	.9		55,985	1.2	35,965	1,506
Wyoming	1,125,332	29,416	1,114,414	1,098,148	13,071	24.2	26,495	22,068	3,845	1.7		12,500		5,116	
District of Columbia	946,445	181,051	1,127,496	946,445	181,051	6.6									
Hawaii															
TOTALS	115,370,280	47,885,170	130,363,292	103,973,633	21,145,451	2,318.0	30,700,934	9,304,958	17,981,087	264.5	679,387	3,396,634	40.4	1,412,302	5,361,998

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3 – PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF OCTOBER 31 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 2,508,096	$ 1,932,785	$ 550,192	176.1	$ 549,329	$ 61,735	$ 487,594	26.7		$ 22,904	0.3	$ 37,932	$ 4,271
Arizona	599,423	971,211	1,216,816	530,962	573,628	102.3	412,022	59,762	344,389	32.0				8,699	53,134
Arkansas	1,449,634	857,024	1,704,635	1,337,753	354,517	205.8	543,110	79,018	462,095	64.0	$ 32,863	31,680	4.6		8,733
California	3,480,440	1,999,203	5,197,903	3,476,277	924,869	222.2	997,017		943,759	23.8		61,629		4,163	68,946
Colorado	1,718,632	871,502	2,824,503	1,608,632	781,675	295.4	275,492	110,000	89,827	16.1					
Connecticut	659,120	420,868	920,180	659,120	235,769	19.4	140,651		125,141	1.9		58,859	.1		1,099
Delaware	481,113	230,849	527,686	277,564	228,317	68.8	203,783	203,549		2.5					2,532
Florida	1,302,816	1,043,543	1,692,424	1,276,273	394,194	83.3	675,727		624,180	42.1		15,978		26,543	9,191
Georgia	2,360,973	1,278,373	2,146,513	1,935,431	172,808	155.1	613,012	293,138	319,874	44.9		100,176	4.0	92,404	685,515
Idaho	1,121,562	824,460	1,891,835	1,094,530	611,868	217.5	136,457		136,457	6.7		76,125	.3	27,032	
Illinois	5,780,033	4,282,273	7,029,186	5,273,713	1,683,718	373.4	2,691,497	468,420	2,223,077	128.3		90,274	2.6	37,899	285,204
Indiana	731,672	151,473	685,202	604,042	22,167	75.2	174,810	87,850	86,960	24.7				39,380	42,346
Iowa	2,413,368	1,875,000	3,965,234	2,411,257	1,431,019	649.7	456,566		435,400	53.9		1,000	2.2	2,101	7,581
Kansas	2,522,401	1,330,595	3,364,346	2,483,248	877,989	287.6	491,759	39,153	452,606	35.7					
Kentucky	1,837,926	1,557,503	2,898,900	1,813,930	914,379	340.5	692,178		608,088	69.0		29,555	2.5	23,946	5,482
Louisiana	1,426,879	838,953	1,593,860	1,291,973	289,472	69.4	597,350	127,387	469,963	26.7	3,135	74,211	2.5	4,384	5,308
Maine	842,479	445,012	1,397,095	842,403	419,169	104.7	16,332		16,332	.8				75	9,510
Maryland	891,132	1,024,708	1,218,325	876,320	283,690	79.8	269,248	9,909	259,339	11.3		200,111	8.2	4,903	281,568
Massachusetts	488,185	920,000	728,630	474,504	246,398	22.8	590,935		590,935	12.9				13,681	82,667
Michigan	3,184,057	1,713,142	3,809,885	3,025,292	526,975	239.2	1,264,377	117,227	1,128,600	61.4		43,200	2.9	41,538	14,367
Minnesota	2,376,415	1,470,324	3,907,125	2,312,126	1,337,292	403.3	137,996		110,996	13.0				64,289	22,036
Mississippi	1,744,669	354,023	1,383,008	1,366,416	16,500	149.6	559,692	349,342	210,350	46.5		116,646	8.6	28,911	10,527
Missouri	2,923,273	2,363,922	4,305,104	2,828,144	1,390,700	908.2	991,333	93,414	852,163	149.3		121,059	.3	1,716	
Montana	1,859,937	942,434	2,613,003	1,764,962	835,121	313.0	140,462	42,826	97,635	14.0				52,149	9,678
Nebraska	1,957,240	991,091	2,595,465	1,947,268	621,814	449.2	413,643		369,138	54.6		139	.1	9,972	
Nevada	1,136,479	852,000	1,745,185	1,123,828	577,637	215.7	232,198		232,198	20.8		40,000	5.7	12,651	2,165
New Hampshire	477,386	261,593	769,895	475,526	244,016	34.7						11,610	.4	1,860	5,968
New Jersey	55,099	460,000	56,528	55,099		.5	321,492		320,879	2.8					139,121
New Mexico	1,272,129	735,425	1,967,597	1,272,129	693,418	293.3	26,051		26,051	.7					15,956
New York	4,002,686	3,693,000	7,384,831	3,538,046	2,741,939	311.7	1,201,150	327,200	870,400	72.2				137,440	80,661
North Carolina	2,380,573	1,700,340	3,408,235	2,228,195	1,169,844	376.2	674,445	143,949	530,496	54.4				8,429	
North Dakota	1,451,112	734,742	1,529,905	1,330,868	198,200	469.6	434,981	91,607	343,374	104.5	25,629	92,333	11.9	3,008	100,834
Ohio	3,871,148	1,966,253	4,895,840	3,781,486	829,831	375.1	772,760	18,070	722,417	40.0	47,700	323,350	16.8	23,892	90,655
Oklahoma	2,304,199	1,171,295	2,842,275	2,150,656	372,526	296.3	811,029	147,071	623,574	37.4		29,343	.3	6,472	145,852
Oregon	1,526,724	892,176	2,535,214	1,494,881	776,391	173.7	19,526	19,526		.2				12,317	115,785
Pennsylvania	7,411,822	2,639,003	8,936,401	6,538,006	2,069,404	655.2	1,288,961	658,917	553,497	98.0		5,701		214,899	10,401
Rhode Island	497,813	254,040	497,631	447,809	39,789	34.2	211,374		211,374	7.1	50,004		3.0		2,876
South Carolina	1,364,791	1,342,000	1,417,537	1,062,011	327,745	142.4	1,259,359	249,891	990,809	148.0				52,889	23,446
South Dakota	1,502,870	761,911	2,013,290	1,442,863	565,011	592.6	177,456	50,813	126,643	40.3		67,190	7.0	9,194	3,066
Tennessee	2,123,155	1,075,748	2,537,856	1,949,718	479,648	174.2	415,358	103,127	312,231	14.4	3,663	120,014	1.5	66,647	163,855
Texas	6,012,518	3,638,000	8,234,416	5,982,701	1,723,228	956.6	1,893,214		1,893,214	90.4		5,000	14.2	29,817	16,558
Utah	1,048,677	533,173	1,738,377	1,039,141	392,639	236.1	166,380		140,000	16.0				9,536	534
Vermont	438,880	241,354	812,551	435,360	241,354	53.2								3,520	
Virginia	1,736,770	893,188	2,199,326	1,672,495	474,440	254.6	405,183	35,103	357,944	45.8	21,736	12,083		7,437	48,721
Washington	1,080,673	776,603	1,817,676	1,077,997	697,729	124.1	63,750		63,750	.8				2,676	15,124
West Virginia	1,118,559	570,083	1,243,668	1,056,049	142,795	64.2	370,225	57,172	313,053	18.8		29,594	2.4	5,338	84,641
Wisconsin	2,431,220	1,743,354	3,946,579	2,409,749	1,214,719	226.2	556,308		505,107	9.3		18,549		21,471	4,978
Wyoming	1,125,332	571,928	1,513,605	1,122,741	373,375	251.3	198,553		198,553	25.9				2,590	
District of Columbia	972,024	792,791	1,448,986	971,729	477,257	12.2	104,932		104,932	.7		75,395	.6	296	135,207
Hawaii	177,718	351,000	178,209	177,718		4.9	150,713		143,867	4.6					207,133
TOTALS	93,666,378	58,473,436	127,796,572	88,282,376	32,547,175	12,340.3	25,792,186	4,045,176	21,029,261	1,815.9	184,730	1,873,708	103.0	1,154,096	3,023,292

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933.

Report of the Chief of the Bureau of Public Roads, 1934.

DEPARTMENT BULLETINS

No. 136D . .	Highway Bonds. 20 cents.
No. 347D . .	Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.
No. 583D . .	Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.
No. 1279D . .	Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

TECHNICAL BULLETINS

No. 55T . . .	Highway Bridge Surveys. 20 cents.
No. 265T . . .	Electrical Equipment on Movable Bridges. 5 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . .	Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . .	The results of Physical Tests of Road-Building Rock. 25 cents.
	Federal Legislation and Regulations Relating to Highway Construction. 10 cents.
	Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.
No. 191	Roadside Improvement. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . .	Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

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GOVERNMENT PUBLICATIONS

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3

AS OF OCTOBER 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec 204 of the Act of June 16 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 12,379,999	$ 7,688,721	$ 1,543,428	656.9	$ 2,507,534	$ 600,432	$ 1,734,653	102.0	$ 11,886	$ 414,213	13.6	$ 69,093	$ 567,548
Arizona	5,211,960	2,641,935	7,548,280	4,983,509	1,704,363	502.9	1,207,096	208,622	819,720	42.2		6,580	.1	19,828	111,272
Arkansas	6,748,335	3,428,049	8,341,868	5,965,196	1,555,094	456.9	2,329,909	574,467	1,613,555	142.0	149,665	91,006	6.0	59,007	168,395
California	15,607,354	7,932,206	23,805,517	15,123,463	3,731,310	709.8	6,259,684	478,067	3,755,759	63.2		206,319	.7	5,824	238,818
Colorado	6,874,530	3,486,006	10,840,035	6,689,598	3,366,256	629.3	304,320	133,817	94,839	16.1				51,115	24,911
Connecticut	2,865,740	1,454,868	4,078,082	2,859,541	803,552	67.5	497,992		482,471	5.5		58,859	.1	6,199	109,986
Delaware	1,819,088	923,395	2,443,679	1,615,412	776,751	126.8	204,886	203,549	1,102	2.5		42,012		127	103,530
Florida	5,231,834	2,661,343	7,682,112	5,140,557	1,371,817	260.4	1,121,729	29,832	1,002,802	46.9		199,038	1.7	61,445	87,687
Georgia	10,091,185	5,113,491	10,753,157	8,604,509	1,751,097	622.9	2,131,408	1,000,198	1,077,187	98.3	87,819	319,874	15.5	398,660	1,965,333
Idaho	4,486,249	2,277,486	5,987,005	4,403,836	1,250,713	470.8	766,882		764,753	26.1		77,795	.4	82,413	184,225
Illinois	17,570,770	8,921,401	17,693,800	14,625,614	2,593,839	509.5	7,978,674	2,836,052	5,141,806	180.4		378,018	4.2	109,104	807,738
Indiana	10,037,843	5,088,963	10,357,589	9,071,489	862,591	294.3	4,716,337	797,345	3,883,600	193.3	51,719	84,060	2.2	117,290	258,712
Iowa	10,055,660	5,118,361	14,715,150	9,842,955	4,109,230	1,167.6	1,020,278	210,565	754,400	57.6		1,000	2.2	2,140	253,731
Kansas	10,089,604	5,117,675	13,619,078	9,961,125	3,308,084	1,052.6	1,878,497	70,683	1,785,266	89.0	48,919	24,325	2.2	8,878	
Kentucky	7,517,359	3,818,311	9,398,499	6,906,083	1,984,852	702.7	2,187,969	499,535	1,455,360	102.4	40,006	76,769	4.6	71,735	301,330
Louisiana	5,828,591	2,963,932	6,074,075	4,565,560	956,023	182.0	2,507,869	1,058,401	1,407,515	58.8	155,417	545,151	19.2	49,213	55,242
Maine	3,369,917	1,711,586	4,679,782	3,302,096	1,206,200	181.7	526,159	45,122	467,720	11.5				22,699	37,665
Maryland	3,564,527	1,810,058	2,968,820	2,490,108	407,217	108.7	2,182,277	979,303	389,010	26.4		402,384	11.7	95,116	611,448
Massachusetts	6,597,100	3,350,474	6,092,918	4,579,945	934,555	89.5	4,170,306	1,974,333	2,195,973	25.8				42,822	219,946
Michigan	12,736,227	6,452,568	16,814,115	12,485,702	3,463,986	623.3	3,034,502	182,477	2,829,775	139.7		128,248	5.9	68,048	30,559
Minnesota	10,656,569	5,425,551	14,881,801	9,933,719	4,318,900	1,609.4	1,346,392	539,834	645,540	39.6	13,805	205,337	1.8	169,211	255,774
Mississippi	6,978,675	3,540,227	9,013,651	5,477,139	1,067,781	518.5	3,692,423	1,365,390	1,898,631	199.4	5,574	421,181	23.1	130,572	152,634
Missouri	12,180,306	6,173,740	13,274,789	10,597,882	1,886,704	1,193.4	5,731,840	1,452,147	3,936,939	257.3		240,779	.7	130,277	109,318
Montana	7,439,748	3,769,734	10,947,625	7,144,593	3,168,065	991.4	656,728	154,622	502,106	32.3	47,837		7.3	92,696	99,563
Nebraska	7,828,961	3,964,364	11,153,608	7,755,445	2,213,832	941.4	1,962,774	34,041	1,637,550	92.5		10,395	.1	39,475	102,588
Nevada	4,545,917	2,302,356	6,549,397	4,475,445	1,873,496	691.4	385,677	26,150	347,167	60.4		41,650	5.7	44,322	40,042
New Hampshire	1,909,839	969,462	2,807,486	1,836,024	869,856	76.9	64,751		64,751	.4	22,006	11,610	.9	51,809	23,244
New Jersey	6,346,039	3,220,879	6,542,556	5,831,264	354,394	71.6	2,419,290	356,159	1,746,198	16.0		656,846	1.0	158,615	463,441
New Mexico	5,792,935	2,941,700	8,039,581	5,531,998	2,330,027	744.1	527,745	62,414	465,331	24.6	37,087			161,437	146,341
New York	22,330,101	11,327,921	31,754,211	21,106,918	5,648,719	659.4	7,986,263	984,375	4,972,442	163.6	12,000	58,000	.2	226,808	648,761
North Carolina	9,522,293	4,840,941	12,983,083	8,675,058	3,074,834	1,237.6	1,870,333	459,393	1,394,045	108.1	74,297	258,195	4.6	313,545	113,867
North Dakota	5,804,448	2,938,967	7,047,022	5,397,619	1,033,602	1,884.3	923,175	241,742	616,848	155.4	124,619	389,562	65.8	40,468	898,955
Ohio	15,484,592	7,865,012	20,415,092	15,231,198	3,724,403	701.6	3,775,234	161,683	3,301,126	69.0	47,700	648,521	19.9	44,012	190,961
Oklahoma	9,216,798	4,685,180	12,103,278	8,835,902	2,536,818	735.6	2,076,112	366,193	1,650,283	67.4		153,989	1.2	14,702	344,090
Oregon	6,106,896	3,097,814	9,220,393	5,905,905	2,510,076	455.0	605,124	99,039	429,966	10.5	517			101,434	157,772
Pennsylvania	18,891,004	9,590,788	26,798,346	17,816,453	7,828,278	955.0	1,931,615	831,814	1,015,026	108.1	2,126	389,480	1.5	240,611	358,004
Rhode Island	1,998,708	1,014,572	2,676,902	1,944,409	645,325	78.0	215,174		215,174	7.1	50,004	151,196	4.1	4,295	2,876
South Carolina	5,459,165	2,770,954	5,775,244	4,972,835	695,130	440.8	2,036,194	373,302	1,620,082	179.0	15,740	52,612	.2	97,288	403,130
South Dakota	6,011,479	3,047,643	8,316,479	5,692,880	2,075,416	1,442.5	493,369	110,383	382,986	73.2	6,425	466,256	33.9	201,791	122,986
Tennessee	8,492,619	4,302,991	11,205,934	8,109,360	2,198,963	438.7	1,710,951	242,654	1,371,895	42.1	14,917	412,135	3.8	125,688	319,997
Texas	24,244,024	12,291,253	30,989,671	23,308,078	6,223,120	2,500.1	6,509,639	640,814	5,629,501	271.0	265,315	363,130	20.9	29,817	75,502
Utah	4,194,708	2,132,691	6,446,870	4,008,880	1,705,966	567.9	578,122	167,060	287,750	22.7		101,000	.3	18,768	37,975
Vermont	1,867,573	948,007	2,934,878	1,833,963	777,042	134.9	185,029	3,922	166,843	4.7		2,713		29,688	1,410
Virginia	7,416,757	3,765,387	10,659,304	7,116,309	2,722,299	547.3	1,093,945	195,954	802,505	69.6	42,221	71,985	1.5	62,273	168,599
Washington	6,115,867	3,106,412	8,003,783	5,902,257	2,010,280	289.0	1,342,211	198,743	1,016,791	13.8		8,093		14,867	71,248
West Virginia	4,474,234	2,280,335	5,167,023	4,159,038	861,104	182.6	1,243,596	279,824	930,783	33.3		81,403	2.6	35,372	407,044
Wisconsin	9,724,881	4,941,837	14,145,338	9,619,596	3,855,813	589.0	1,220,351	41,802	979,141	30.2		97,661	1.2	63,483	9,222
Wyoming	4,501,327	2,287,712	6,204,518	4,442,784	1,576,344	932.0	731,432	48,941	655,752	105.6		50,372		9,603	5,244
District of Columbia	1,918,469	973,842	2,576,482	1,918,173	658,309	18.8	104,932		104,932	.7		75,395	.6	296	135,207
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,291,097	681,972	436,870	18.3	20,973	276,443	1.8	37,497	236,465
TOTALS	394,000,000	200,000,000	516,412,853	366,616,763	108,125,854	31,076.5	102,246,426	22,003,167	70,882,220	3,705.6	1,348,594	8,751,590	295.0	4,031,476	12,240,336

U. S. GOVERNMENT PRINTING OFFICE: 1935

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

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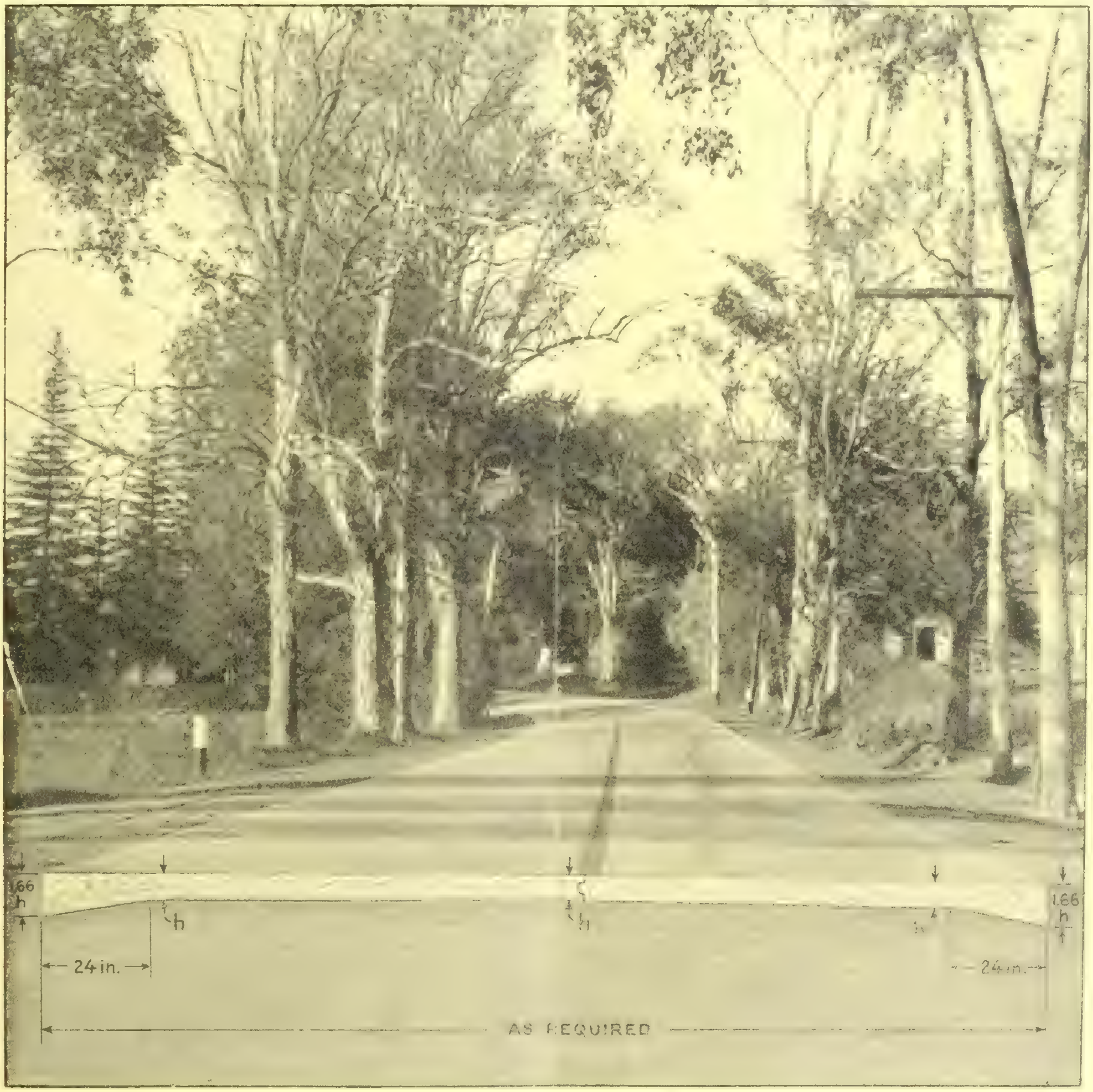

A CONCRETE ROAD WITH A CROSS SECTION BALANCED FOR LOAD STRESSES

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by L. W. TELLER, Senior Engineer of Tests; and EARL C. SUTHERLAND, Associate Highway Engineer

PART 3.—A STUDY OF CONCRETE PAVEMENT CROSS SECTIONS

DEVELOPMENTS in the design of cross sections for concrete pavements during the past 15 years have produced such marked improvements in the roads constructed that one is likely to feel that a high degree of perfection has been attained. Edge thickening and longitudinal joints have been generally adopted and the present slab lengths are much less than those formerly used.

The most complete study yet made of the stresses in typical pavement slabs resulting from both load and temperature effects confirms the belief that progress has been made in the right direction, but it is clear that better designs are possible with the more complete knowledge now available.

The results of this study are surprising as to the stresses that will exist in concrete pavements with certain combinations of load, temperature conditions, and slab thickness. However, the conclusions are thought to be sufficiently well established for application in current design.

If loads alone are considered, the maximum of economy in the use of material is obtained with a thickened-edge cross section.

While increased edge thickness results in a reduction of the edge stresses from applied load, it also causes an increase in the edge stresses under certain conditions of restrained warping.

Since a balanced cross section should in all cases be designed on the basis of combined load and warping stresses, it is obvious that economy demands that the stresses resulting from warping be limited to low values. The most practical way of doing this is by constructing short pavement slabs.

In short slabs the cross section may be designed on the basis of load alone.

A balanced cross section for load stresses is obtained with a design such as is shown on the cover page.

Edge thickening strengthens slab corners regardless of the length of the slab.

At the present time application of the principles set forth above to the design of pavement slabs involves considerations other than those discussed in this report but necessary to the forming of a correct judgment as to whether or not a completely balanced design should be used or how closely it should be approached.

THE SHAPES of the cross sections used in concrete pavement construction in the United States have gone through an interesting period of development during the last 15 years.

The earliest concrete pavements were laid in slabs that were either thicker in the center than at the edges or else were of uniform thickness at all points. The thick-center-thin-edge design was probably the result of the influence of the distribution of material in those macadam pavements with which engineers were most familiar at the time the early concrete pavements were laid.

Some of the first attempts at a mathematical analysis of the stresses created by wheel loads in the pavement slab treated the transverse section as a beam supported at the ends, and this type of analysis naturally indicated the need for a section which was thicker in the center than at the edges. The uncertainty of assumptions as to subgrade support tended to make engineers hesitant about accepting the suggested theories of design, with the result that a considerable amount of the concrete pavement laid was of a uniform thickness.

Upon the entry of the United States into the World War, the wheel loads on many of our main roads suddenly increased greatly, and instances of edge failure of thin-edge sections began to be reported. These edge failures frequently began with a corner break at a construction joint or transverse crack and often developed into a completely shattered area of considerable size. Many engineers began to suspect that the thick-center-thin-edge pavement was not properly designed.

DEVELOPMENT OF THICKENED-EDGE PAVEMENT DESIGN REVIEWED

On November 12, 1920, in Maricopa County, Ariz., construction was begun under a very extensive paving program, including some 130 miles of concrete pavement. The point of particular interest is that the cross section adopted for the entire project was 3 inches thicker at the edges than at the center, the edge thickening being gradually reduced to zero at a distance of 24 inches from the edge of the slab. The report on this work[1] states that the cross section was "a modified inverted-curb section designed to strengthen the edge and at the same time permit simple construction of the subgrade. The thickened edges add structural strength as the area of load distribution and subgrade resistance decreases, thereby securing a paving slab with a more uniform resisting strength." This is clearly a recognition of the principle of design of thickened-edge slabs as we know it today.

The development of the thickened-edge design created widespread interest among highway engineers and, as the probable worth of the new design began to be appreciated, it was adopted for trial in a number of places.

The test road at Pittsburg, Calif., built during the summer of 1921, contained one section of the new design, and at the conclusion of the test this section was given the highest rating of all of those included in the track.[2]

The sections of the Bates test road in Illinois laid in 1920 and 1921 contained no thickened-edge designs but, fortunately, in the fall of 1922 sections of the new design were added and subjected to heavy traffic during 1923.[3] The result was another early demonstration of the superiority of the new design over sections of uniform thickness when subjected to concentrations of heavy wheel loads. In this test the structural weakness of the edges of slabs of uniform thickness was definitely shown.

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[1] Pavement With Thickened Edges Takes Heavy Loads, by C. L. Jenken. Engineering News-Record, Apr. 13, 1922, p. 607.

[2] Report of Highway Research at Pittsburg, Calif., by Lloyd Aldrich and John B. Leonard. California State Printing Office, Sacramento, Calif., 1923.

[3] Highway Research in Illinois, by Clifford Older. Transactions, American Society of Civil Engineers, 1924.

The Bureau of Public Roads at about this time developed a method for determining the stresses in concrete pavement slabs caused by wheel loads and, during 1923 and 1924, made a number of studies of stress.[4] The data obtained from these tests indicated clearly the soundness of the thickened-edge design from a load-carrying standpoint.

The fact that concrete possesses definite elastic properties has led to several attempts to develop some mathematical analysis that would make possible the prediction of the stresses caused by load in a given pavement slab design. The most serious obstacle encountered in these efforts was the difficulty in treating rationally the conditions of subgrade support. It was not until Westergaard presented his analysis of the stresses in a concrete pavement slab in 1925 that there was available an even approximately tenable theory of design.[5] In this analysis it is assumed that the load is applied over a definite area to an elastic slab that rests upon an elastic support. By means of the formulas presented it is possible to calculate the critical stresses resulting from a given load applied at the corner, at the free edge, or in the interior of the slab.

The analysis indicated that for the assumed conditions a thickened-edge design is necessary if the section is to offer uniform resistance to load at all points, thus confirming the evidence obtained from the field tests and stress measurements.

The analysis showed for the first time how important a factor the area of load application is in determining the magnitude of the critical stress. It was not possible however, to determine the correct shape of the slab cross section, nor was the means provided for determining the value of the elastic constant that should be used for a given subgrade in the practical application of the analysis to specific cases of design. In spite of these deficiencies the Westergaard analysis represents one of the most important steps in the development of concrete pavement slab design.

By 1924 several progressive States that were building considerable mileages of concrete pavement had adopted as a standard some form of thickened-edge design, but there was a wide variety of opinion as to what the shape of the cross section should be. Today, a decade later, 41 States are using exclusively some type of thickened-edge design and there still appears to be a considerable divergence of opinion as to the amount and distribution of edge thickening needed, the reason being that neither theory nor experiment has so far supplied the information to enable engineers to design with precision a cross section with equal resistance to applied load at all points.

FACTORS AFFECTING CROSS-SECTION DESIGN INVESTIGATED

The investigation of the structural action of various concrete pavement slab designs which was begun in 1930 by the Bureau at the Arlington Experiment Farm included, as one of its major parts, a study of the behavior of a number of designs of pavement cross section.[6]

While it is usual to think of the design of a cross section as being determined by the variation in the bending moments resulting from applied load, in pavements, as in other structures, other factors must also be considered if a satisfactory design is to result.

Most of the data relating to the effects of temperature variations have already been presented,[7] and in the attending discussion the primary importance of these effects has been brought out. In this study of pavement cross sections particular attention has been given to the following:

1. The effect of the condition of warping on the stresses caused by applied loads.
2. The effect of the changes in the supporting power of the subgrade caused by freezing and thawing or by other causes.
3. The stresses caused by variations in the temperature conditions within the pavement.

While the discussion naturally centers around the load-stress relations developed for the various cross sections, consideration is given to the effects of each of the factors just mentioned as observed in the tests at Arlington.

The sections selected for these tests have already been described in part 1 of this series of papers, but for the convenience of the reader the details of the various cross sections are again shown in figure 1. It will be observed that the sections shown cover fairly well the range of designs in use in this country today. There are four sections of uniform thickness (6, 7, 8, and 9 inches thick). This type of slab is still in use in seven States. There are three thickened-edge slabs of the type in which the edge thickening is reduced at a uniform rate to zero at a short distance from the edge. This general type is used in 28 States at the present time. The parabolic cross section, in which the thickening extends to the center of the slab, is used in 9 States, while the design suggested by the American Association of State Highway Officials (sec. 3 in fig. 1) is used in 1 State.

Although the actual dimensions of the cross sections used by some of the States will be found to differ somewhat from those of the sections shown in figure 1, the differences are not large and it is believed that complete tests on these sections provide adequate data upon which to base a judgment as to the efficiency or balance of almost any of the cross sections in use in the United States at the present time.

PROGRAM OF LOAD TESTING DESCRIBED

The schedule of load testing followed in developing the data on the relative efficiency of the several cross sections can be most readily explained by referring to figure 2, in which the four quarters or quadrants of one of the 20- by 40-foot test sections are shown. In this figure the small circles indicate the points where a load was applied, the load being placed successively on each point beginning at the free edge of the panel; the short lines within the circles in quadrants 1 and 3 show the position and direction of the strain gages; and the broken line A′—B′ in quadrant 4 is the line along which the curvature of the slab was measured. The loading schedule shown in quadrant 1 was followed on at least 1 quadrant of each of the test sections and on more than 1 quadrant if thought desirable. The schedule shown in quadrant 3 was followed on all four quadrants of all of the test sections. Deflection measurements

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[4] Stress Measurements in Concrete Pavements, by L. W. Teller, Proc. Fifth Annual Meeting Highway Research Board, Dec. 3-5, 1925.

[5] Stresses in Concrete Pavements Computed by Theoretical Analysis, by H. M. Westergaard. A paper presented before the Highway Research Board, Dec. 3, 1925. Also see PUBLIC ROADS, vol. 7, no. 2, April 1926.

[6] See The Structural Design of Concrete Pavements, pt. 1, by L. W. Teller and Earl C. Sutherland, PUBLIC ROADS, vol. 16, no. 8, October 1935.

[7] See The Structural Design of Concrete Pavements, pt. 2, by L. W. Teller and Earl C. Sutherland, PUBLIC ROADS, vol. 16, no. 9, November 1935.

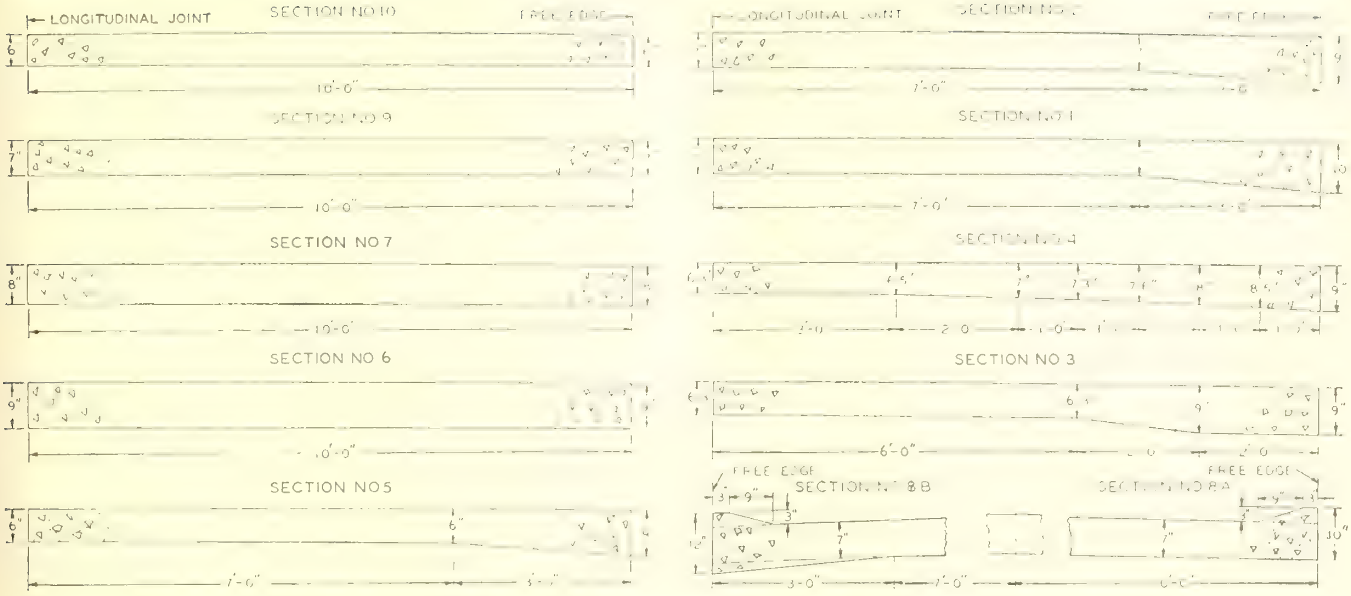

Figure 1.—Designs of Pavement Cross Sections Studied.

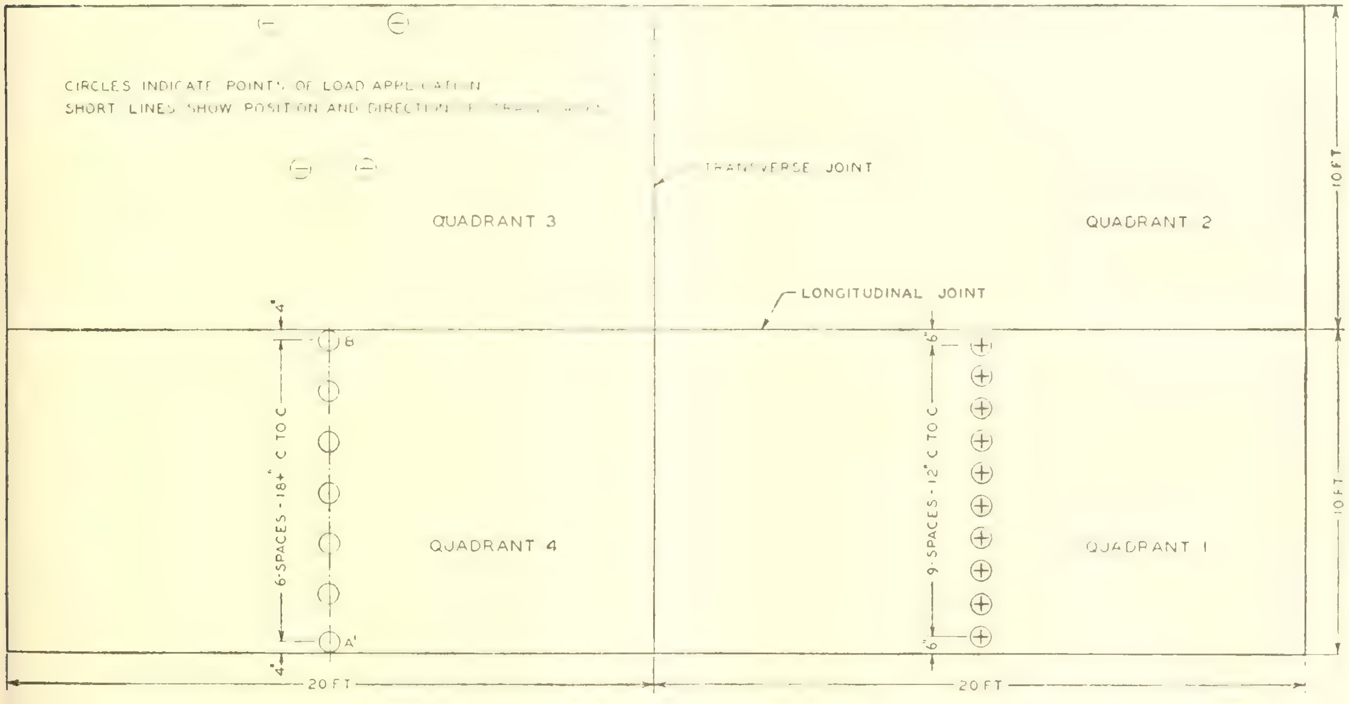

Figure 2.—Points Where Loads Were Applied and Deflections and Strains Were Measured.

were made on one quadrant of each test section. On a number of the sections load-stress data were obtained during the different seasons of the year, particularly to determine the effect of subgrade condition.

In all of these loadings a bearing block 8 inches in diameter and of the grooved type was used in order that both deflection and strain measurements might be made within the area of load application. Because of the height of the clinometer it was necessary to use a split bearing block approximately 4 inches in height when making deflection measurements. The method of applying the load for deflection and strain measurements is shown in figures 3 and 4, respectively.

For the loading schedule shown in quadrant 1, recording strain gages of the type described in part 1 of this series of papers were installed at each of the 10 positions, being placed either all transversely or all longitudinally in any one test. The selected load was then applied successively at each of the 10 points, the strains in both the longitudinal and transverse directions being recorded at each gage position for each loading.

The tests scheduled in quadrants 1 and 4 were actually performed in the same quadrant of the test section in order that the closest possible relation would exist between the strain and deflection data.

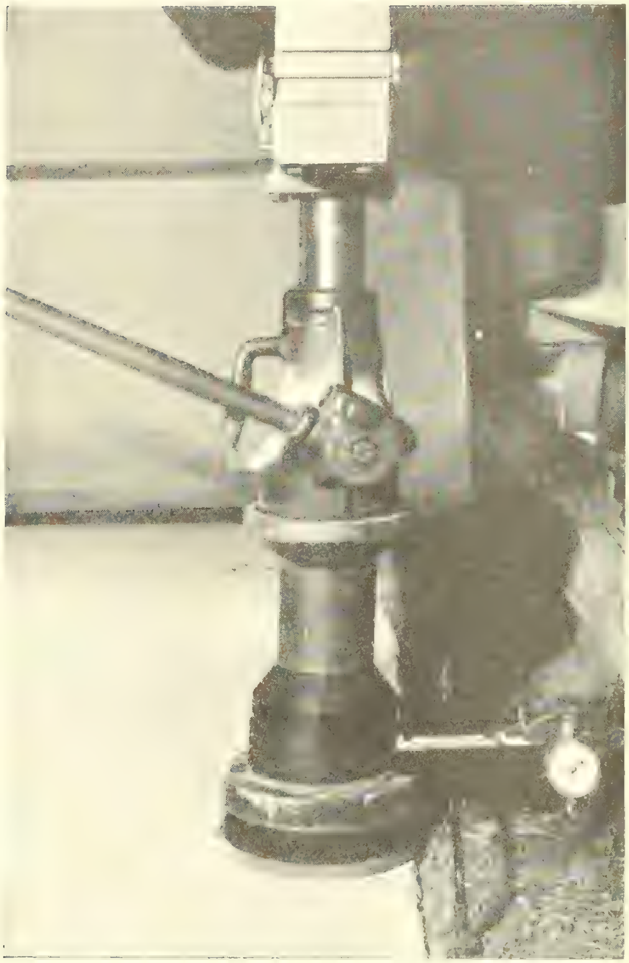

Figure 3.—Applying a Test Load at the Edge of a Slab Panel. The Deflections Were Referred to a Bench Mark Located in the Shoulder.

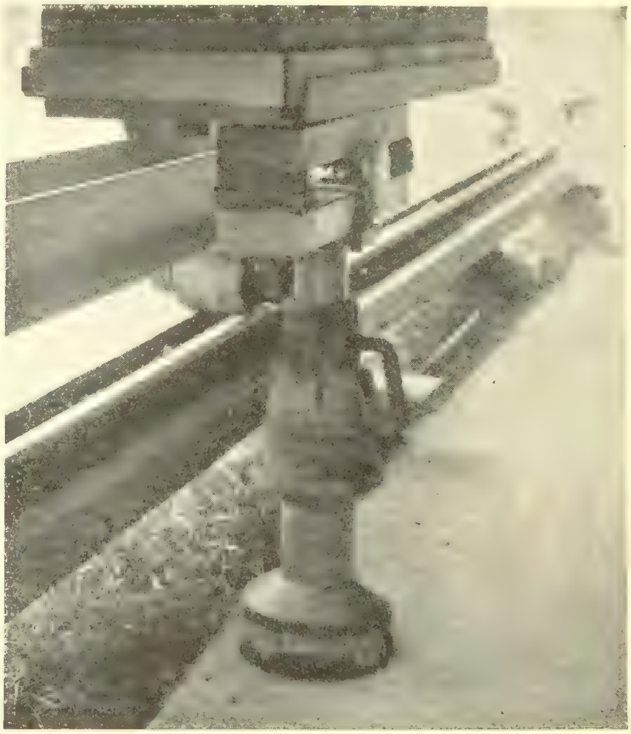

Figure 4.—Strain Measurement With Load Placed Nea Edge of Test Section. A Recording Strain Gage i Installed Directly Under the Load in a Direction Perpendicular to the Edge of the Slab.

All of the deflection data were obtained with a 10-inch clinometer using the procedure described in part 1 of this series of papers. The measurements were started at a bench mark set close to the edge of the test section (see fig. 3) and were continued entirely across the slab. The elevation of each clinometer point, with respect to the bench mark, including that directly underneath the load, was thus determined and the true shape of the transverse center line of the slab established. This determination was made first with no load upon the slab and again after the given load had been applied, the difference between the two curves at any point being the vertical deflection of that point caused by the applied load. In this manner the deflection of the slab between points A′ and B′ (see fig. 2) was obtained for a load acting at each of the several loading points.

Only a short period of time was permitted to elapse between the strain and the deflection measurements in order that the condition of the slab might not change.

LARGE DEFLECTIONS AND STRAINS OBTAINED WITHOUT OVERSTRESSING CONCRETE

It was desirable to use loads of sufficient magnitude to cause large deflections and large strains in the concrete since this would reduce the error of measurement. On the other hand, it was necessary to put a limit on the strains produced by loading since it was very important that no injury be done to any of the test sections. It was decided to limit the loads applie to the extent that the maximum stresses produce in the concrete would not, in general, exceed one-hal of the average modulus of rupture as determined b the strength tests made at the beginning of the investigation. This criterion has proved to be satisfactory With but one exception, all of the forty 10- by 20-foo test slab panels are apparently intact after 4 years o intensive load testing. The strains and deflection produced by loads of this magnitude were of sufficien size that they could be measured with satisfactor accuracy with the instruments available.

In the preceding paper it was shown that the condition of warping of a pavement slab had a definit effect upon the magnitude of the maximum stress given load might be expected to produce, particularl if the load were applied at the corner or along the edge of the slab. It has also been established that, for th concrete used in this pavement at least, the moistur condition in the concrete had an important effect upo its elastic properties. These two facts made it necessary to take special precautions to maintain unifor conditions of moisture and of temperature within the co crete of the test sections during any period of load testin

As previously described, the method adopted f protecting the slabs during these tests consisted of covering layer of approximately 4 inches of dry stra laid directly on the concrete, with protection from rai snow, or direct sunlight afforded by a large canv shelter supported by a framework on the loading tan

Temperature measurements made within the co crete of the slabs thus protected showed that the diffe entials in temperature between the upper and low surfaces of the pavement were always very small, fr quently so small as to be unmeasurable. At the tim of testing there could have been but little if any tem perature warping present in the test sections. It wa not possible to determine the variation in moisture throughout the depth of the concrete in the slabs and therefore no positive statement regarding the condition of moisture warping can be made. It seems reasonable, however, that the dead-air spaces in the dry straw layer which provided the thermal insulation would also greatly decrease the rate of moisture evaporation from the surface of the concrete and would reduce correspondingly the tendency for a differential in moisture content to develop. Whatever differential may have existed was held constant during the period of test by this method of protecting the test section.

FORMULAS FOR CALCULATING LOAD STRESSES GIVEN

The strength and elastic properties of the concrete were determined by tests made upon drilled cores and sawed beams obtained from short sections of pavement constructed especially for this purpose at the same time that the test sections were constructed. One of the matters investigated in these collateral tests was the effect of moisture on the stiffness of the concrete, and it was found that the value of the modulus of elasticity varied to some extent with the moisture content, being highest for moist concrete. The details of these tests will be covered in a subsequent paper. It was decided as a result of the tests that the proper value of the modulus of elasticity of the concrete, in bending, and containing as nearly as could be determined the same percentage of moisture as the concrete in the test sections, was 5,500,000 pounds per square inch. This value is used throughout this series of papers in computing stress values from the measured strains.

If a load is applied at a certain point on a pavement slab, the stresses developed at the point of load application can be determined from measured strains by means of the following formulas as described in part 2 of this series of papers:

$$\sigma_x = \frac{E}{1-\mu^2}(e_x + \mu e_y) \qquad (1)$$

$$\sigma_y = \frac{E}{1-\mu^2}(e_y + \mu e_x) \qquad (2)$$

in which σ_x = the stress in the direction of the x-axis.
σ_y = the stress in the direction of the y-axis.
e_x = the unit deformation caused by stress in the direction of the x-axis.
e_y = the unit deformation caused by stress in the direction of the y-axis.
E = the modulus of elasticity of the concrete.
μ = Poisson's ratio for the concrete.

The value of Poisson's ratio was not determined for these tests but was assumed as being 0.15, which seemed to be a fair average value considering such test data as are available.[8]

In carrying out the test schedules described in the preceding paragraphs, a large number of observations were made. In all cases tests were repeated on the same or a different quadrant of the test section until the data obtained were considered to be well established. On some sections more tests were necessary than on others and in certain cases it was deemed desirable to repeat the tests under both summer and winter conditions. It is neither practicable nor desirable to present all of the data which were obtained, but an effort has been made to include all significant data and to show representative data in all cases.

It has been found that the stresses caused by load in the vicinity of the longitudinal joint are affected to a considerable degree by the structural action of the joints. In designing a cross section, therefore, the shape of that portion immediately adjoining the longitudinal joint will be controlled by the design of the joint. Since the characteristics and design of joints are to be discussed in a subsequent paper, it is thought advisable to eliminate from the present discussion detailed consideration of the effect of the joint design upon the cross section. For this reason the data pertaining to that portion of the pavement within 3 feet of the longitudinal joints have been omitted (except in the case of the influence lines). There is every indication that at 3 feet from the longitudinal joint the effect of the joint action is so small as to be unimportant in all cases.

DEFLECTION AND STRESS VARIATION DATA OBTAINED FOR THE VARIOUS CROSS-SECTION DESIGNS

Figure 5 shows deflection curves along a transverse section for a slab of uniform thickness and for one of a conventional thickened-edge design. The magnitudes and positions of the load that produced the deflections are indicated in each case, and attention is called to the difference in the magnitude of the loads used in the two designs. These data show that the slabs are tipped slightly when the load is applied at the free edge, the opposite edge or center of the pavement being actually raised slightly. When the load is applied in the center of the 10-foot section the slab is deflected over practically its entire width. Both of these effects are probably due to the comparative narrowness of the slab. The width, however, is typical of modern pavement construction. It is possible that the narrowness of the panel affects somewhat the elastic curvature and hence the stresses caused by a given load. This point has a bearing on any comparison of measured stresses with stresses calculated by an analysis that assumes an infinitely large panel.

The deflections of the thickened-edge slab are much smaller than those of the slab whose thickness is constant, for loads applied near the free edge. As the load is moved away from the edge, however, this difference decreases, becoming very small at a point 7 feet from the free edge.

Figure 6 shows longitudinal and transverse stresses produced by the same loads on the same two test sections for which deflection data were presented in figure 5. Each curve shows the variation of stress across the transverse section for the magnitude and particular position of load indicated. Longitudinal stress is measured parallel to the long axis of the pavement slab and transverse stress is measured perpendicular to it. These values are based on strains measured in the upper surface of the pavement and hence apply only to that surface. The corresponding stresses in the lower surface of the pavement would be of opposite sense and of very nearly the same magnitude.

AREA OF LOAD INFLUENCE FOUND TO BE RELATIVELY SMALL

It will be observed, from an examination of the stress variation diagrams of figure 6, that a load applied at the free edge of a pavement slab produces two quite different stress conditions in the vicinity of the load. In the transverse direction the section acts somewhat as a cantilever and a fairly high transverse tensile

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[8] See Digest of Test Data on Poisson's Ratio for Concrete, by Richart and Roy. Proc. A. S. T. M., vol. 30 (1930), pt. I, Report of Committee C–9, pp. 661–667

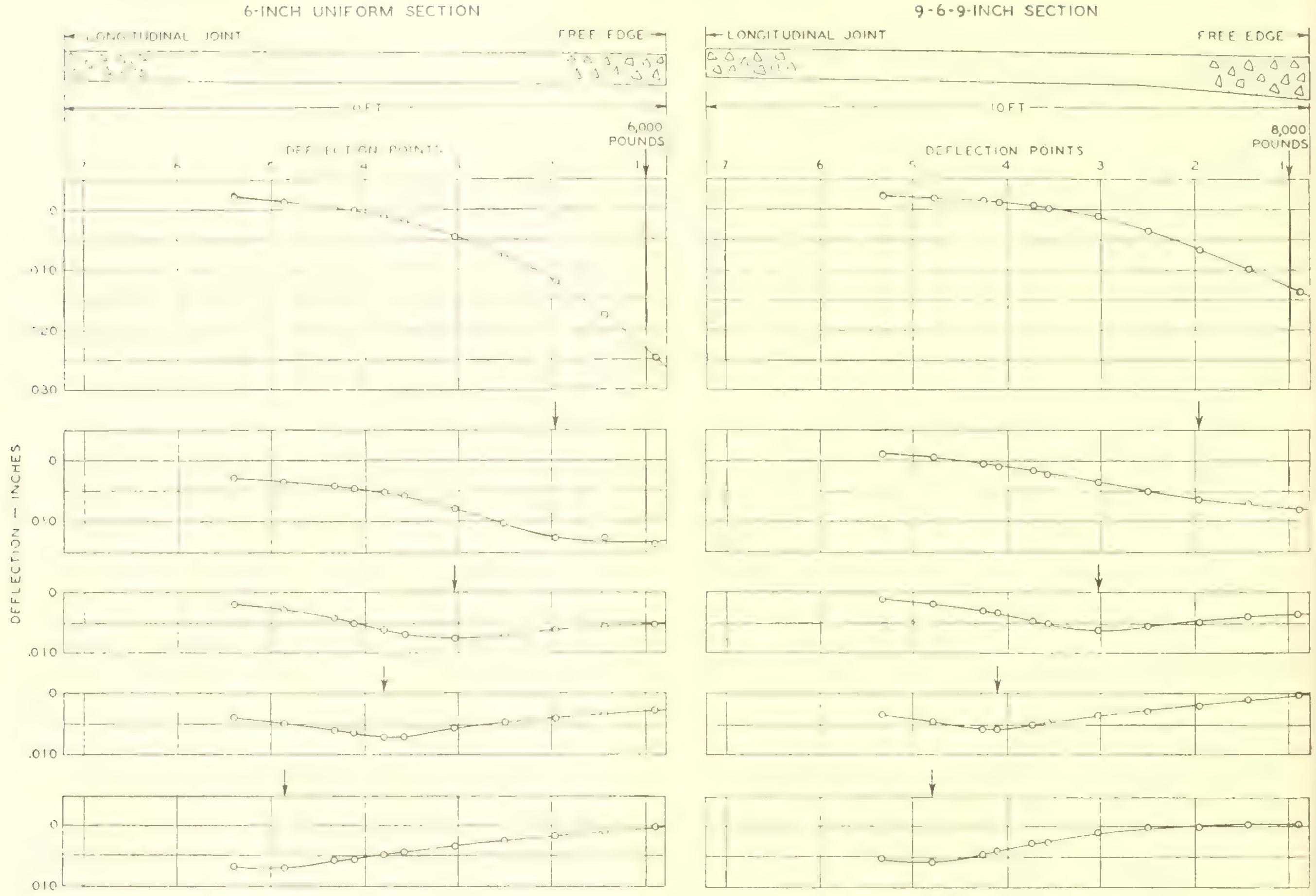


Figure 5.—Elastic Curves for Two Typical Cross Sections for Various Positions of Load.

stress is produced in the upper surface of the pavement, this stress reaching its maximum value at a distance of approximately 2 to 3 feet from the free edge. In the longitudinal direction, the maximum stress produced by the edge loading is a tension in the bottom of the pavement directly underneath the loaded area, with a corresponding compression in the upper surface. For the condition of these tests, in the case of the 6-inch uniform-thickness section, the magnitude of maximum longitudinal stress caused by edge loading is about 3½ times the magnitude of the corresponding maximum stress in the transverse direction and, in the case of the 9–6–9 section, about 6 times that in the transverse direction.

As the position of the load is moved gradually along a transverse section, the stress conditions created change from those just described to those of an interior loading. A load applied at the interior of a panel of infinite extent will cause deflection and stress conditions which do not vary with direction. Even on a panel of the limited dimensions used in these tests, it will be noted that when the loaded area is near the center of the panel the magnitudes of the maximum longitudinal and transverse stresses are practically equal. The variation curves reflect the effect of slab dimension, however, in that for loads applied near the center of the panel the slab is stressed for a somewhat greater distance in the direction of the long dimension than it is in the direction of the short dimension. These curves also show quite definitely that for the interior loading the critical stresses are highly concentrated and that the magnitude of the stress decreases rapidly as the distance from the center of load application increases.

The area of influence of the load, i. e., the area within which appreciable stresses or deflections are produced, will naturally vary with the thickness and design of the cross section and perhaps with other factors. For the designs studied in these tests the data indicate that for the edge loading the area of influence for stresses is roughly a semicircle with a radius of approximately 3 feet, while for the interior loading the area of influence is roughly a circle with a radius of approximately 3 feet. These are only approximate values but the point of interest is the contrast with the areas over which appreciable deflections occur.

The data show that increasing the thickness of the slab near the free edge is an effective method for reducing the maximum stress that can be caused by an applied wheel load. The greatest reduction is thus found in longitudinal tension on the bottom of the slab with the load applied at the free edge of the pavement. There is also a slight reduction in the longitudinal stresses in the interior of the slab which is probably caused by a stiffening effect from the thickened edge.

MAXIMUM DEFLECTION AND MAXIMUM STRESS DIAGRAMS CONSTRUCTED

If a given load is applied successively at a series of positions across a transverse section of a pavement slab, for each position of the load a certain maximum deflection and a certain maximum stress will be pro-

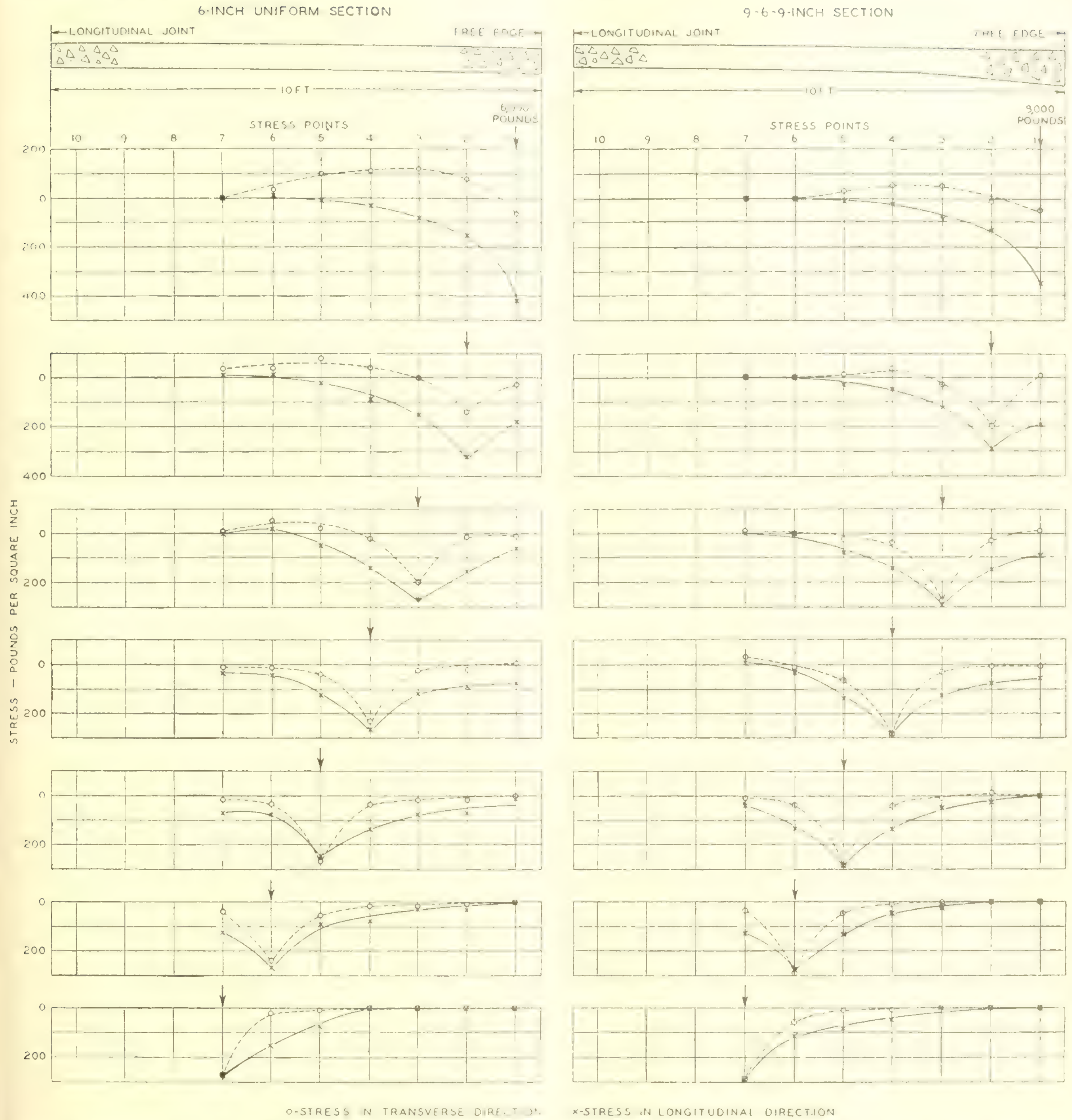


FIGURE 6.—STRESS VARIATIONS IN TWO TYPICAL SECTIONS FOR VARIOUS POSITIONS OF LOAD. VALUES ABOVE THE AXIS INDICATE TENSION AND VALUES BELOW THE AXIS INDICATE COMPRESSION IN THE UPPER SURFACE OF THE SLAB.

duced and the values of these can be determined. If these maximum values are plotted as ordinates at the points on the transverse section at which they were observed, a curve may be drawn through them which is in reality the envelop of all the deflection (or stress) variation curves that might be developed along the section by the load in question. Since this envelop curve shows the maximum deflections (or stresses) that could be developed by the given load regardless of its position, these graphs have been termed maximum deflection (or stress) diagrams in this paper.

Figure 7 shows maximum deflection diagrams for each of the 10 test sections. It should be noted that the diagrams apply only to the case of a single load and that the magnitude of this load varies with the design of the cross section under test.

Sections 10, 9, 7, and 6 are the sections of uniform thickness. The data from these sections show that the maximum deflection caused by a load applied at the free edge of a constant-thickness slab is slightly more than 3 times the maximum deflection caused by a load of the same magnitude applied at an interior point.

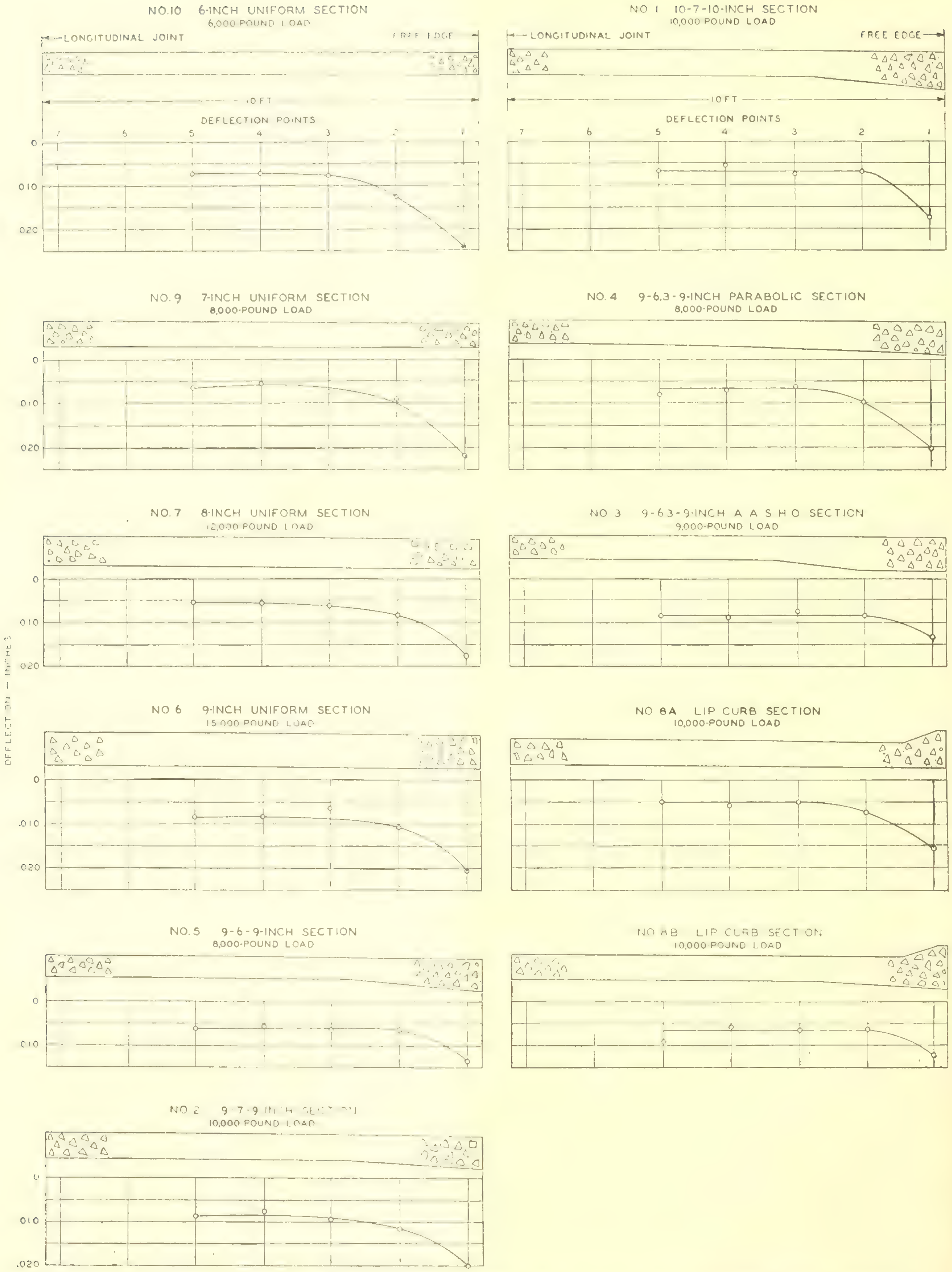


FIGURE 7.—MAXIMUM DEFLECTION DIAGRAMS FOR EACH OF THE VARIOUS CROSS-SECTION DESIGNS STUDIED.

As the area of load application is moved from the free edge toward the interior the magnitude of the maximum deflection decreases rapidly until, with the center of load application approximately 3 feet from the edge, the maximum deflection is practically the same as it is for the load at the mid-point of the panel.

Sections 5, 2, and 1 are thickened-edge sections of the type in which the edge thickening is decreased at a uniform rate to zero at a short distance from the edge. The shape of the maximum deflection diagram for this type of section appears to be very similar to that of a section having a constant thickness, although the maximum deflection with the load applied at the edge of the slab is in this case on the average only about 2.35 times the maximum deflection measured for the same load applied at the interior of the panel. It is apparent that the edge thickening of these sections has a relatively small effect on the maximum deflections.

Section 4 is one in which the cross section is bounded by two parabolic curves, the center thickness being seven-tenths of the edge thickness. The edge deflection of this section is also approximately three times the deflection at the interior.

Section 3 has a heavy-edge cross section of a design once suggested by the American Association of State Highway Officials. The deflection of a slab of this design under an edge loading is approximately one and one-half times the deflection under an interior loading.

Section 8 is the section having the lip curb on the upper surface. As previously explained, two panels of this section (called sec. 8A) had the lip curb added to a slab of otherwise constant thickness while the remaining two panels were of the thickened edge type before the addition of the lip curb (sec. 8B in fig. 1). The deflection of the edge of section 8A is a little more than 3 times the deflection of the interior, while in section 8B the deflection under an edge loading is approximately 2 times the deflection under the same load at the interior of the slab.

These data show that in all cases a given load caused greater deflections when applied at the free edge of the pavement than when applied at the interior points. If the magnitude of the deflections were to be used as a criterion for balancing a design, one might conclude that none of the sections has been strengthened sufficiently along the free edge. It will be of interest to keep these curves in mind while examining the indications of the stress data which follow.

The maximum stress diagrams shown in figure 8 were prepared in a manner similar to that used in developing the deflection data just discussed. These curves show the variations in the maximum longitudinal and maximum transverse stresses as the given load is placed successively at the points shown in figure 2, quadrant 1. The stresses are those directly under the load and generally are the maximum in each direction, the one exception being the transverse stress developed by the load applied at the edge of the slab. In this case the maximum transverse stress is developed 2 or more feet from the edge of the pavement. Because of the fact that a greater transverse stress is developed at the same point when the load is placed directly over it, the exception noted above does not affect the accuracy of the maximum stress diagrams of figure 8.

The values plotted in these diagrams are generally the average of two sets of determinations (the data such as are shown in figure 6 being considered as one set) from tests made on one or two quadrants of the test section. In order to provide a general check and to determine more closely the relation between the maximum stresses resulting from edge and interior loadings, the test schedule shown in quadrant 3 of figure 2 was carried out on all 4 quadrants of all the sections, except section 8, the lip-curb design, where only 2 quadrants of each type were available.

MORE UNIFORM LOAD-STRESS DISTRIBUTION FOUND ON THICKENED-EDGE DESIGNS

In general, the average maximum stresses for the edge and interior loadings as determined by these supplementary tests agree closely with corresponding values determined during the measurements mentioned above, i. e., the schedule shown in quadrant 1, figure 2. The measurements that determined the stress variation curves give a good indication of the variation in strength in the various parts of the different cross-section designs. The supplementary tests, although they involve measurements at only the two positions on the cross section (the free edge and the interior), were made at a considerable number of points. For this reason, the average values for each test section (shown as triangular points in figure 8 and some of the other figures that follow) are believed to give the most reliable indication of the relative strengths of the edge and interior of any particular design. Some discrepancies may be noted in this figure, if a comparison is made between the stresses found in different test sections having comparable edge or interior thicknesses. These discrepancies are believed to result in large part from the fact that different sections were tested at different times of the year.

There were variations in the condition of the concrete and of the subgrade that influence these data to some extent so far as the relation between slab thickness and stress caused by a given load is concerned. Other data obtained within a relatively short period of time were used in the comparison of slab thicknesses to be discussed in a subsequent report. Since all of the tests on any one section were made during a short period of time, it is believed that the effect of the seasonal variations in slab and subgrade condition do not enter any of the comparisons that are made in this discussion of pavement cross sections.

If a pavement cross section is to carry loads with a maximum of efficiency, the design, insofar as applied loads are concerned, should theoretically be such that a given load will produce a certain maximum stress regardless of the point of application of the load on the slab. The maximum stress diagram for such a design would have the same ordinates at the free edge, the interior, and all intermediate points. Any variation in the magnitude of the maximum stress at different points across the section is an indication of too much or too little strength at that particular point. The maximum stress diagrams can be used, therefore, as a basis for judging the efficiency or "balance" of the various cross sections that were tested.

Sections 10, 9, 7, and 6 have a uniform thickness at all points. Referring to the stress diagrams for these sections in figure 8, it will be observed that the shape of the curves showing the variation in maximum stress across the slab are very similar for these four sections. An increase in the magnitude of the maximum stress in the longitudinal direction as the position of the load approaches the free edge of the slab is apparent in all of the sections, showing clearly the lower load-carrying capacity of this portion of a slab of uniform thickness

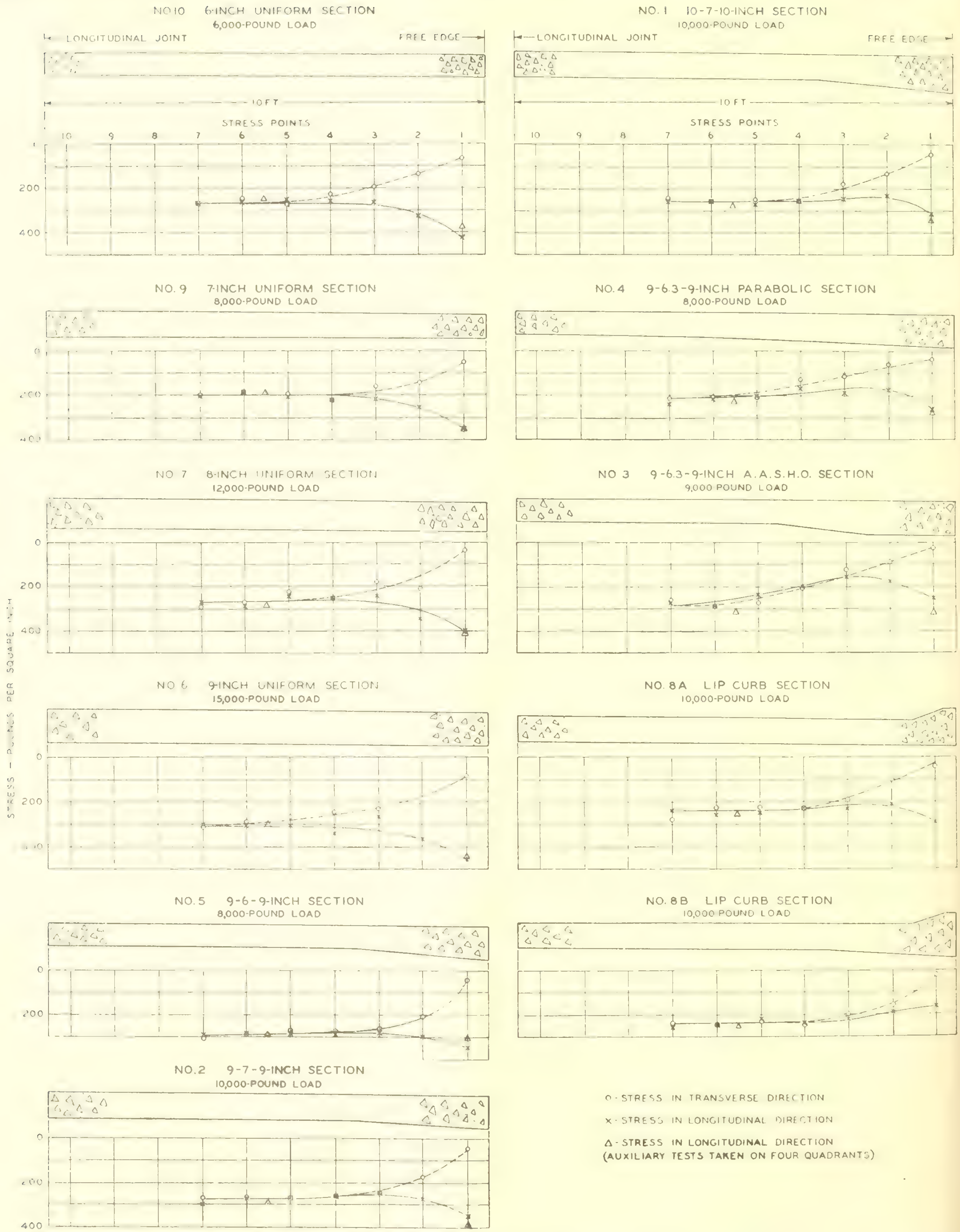


Figure 8.—Maximum Stress Diagrams for Each of the Various Cross-Section Designs Studied. Values Indicate Compression in the Upper Surface of the Slab.

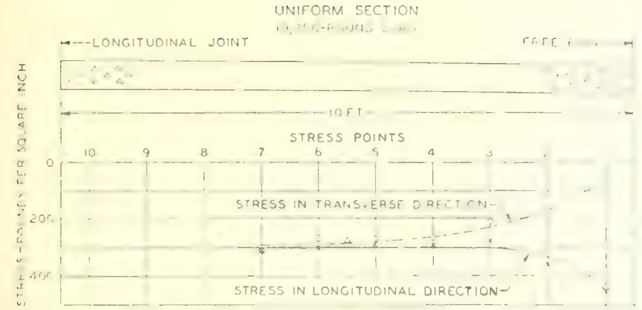


Figure 9.—Maximum Stress Diagrams for Uniform-Thickness Sections Developed From Data Obtained for Sections Nos. 10, 9, 7, and 6.

when load stresses alone are considered. In the transverse direction the stresses are practically zero at the extreme edge of the sections but increase to their maximum value in a distance of approximately 4 feet from the edge. In the case of the longitudinal stresses the maximum value is at the free edge and this value decreases over a distance of approximately 3 feet to a minimum value. The maximum value of the transverse stress is equal to the minimum value of the longitudinal stress throughout the interior region of these sections.

The characteristics of a section of constant thickness are possibly shown better by the average diagram of figure 9. This diagram was constructed by assuming that stress varies directly with load and then averaging the maximum stresses that would be caused in each of the four pavement sections by an average load of 10,250 pounds.

These data indicate that there is a relatively large part of the cross section of a slab of uniform thickness over which a given load will produce practically the same maximum stress and that there is only a relatively small part of the cross section adjacent to a free edge that requires modification to "balance" the cross section. It is indicated that this adjustment of cross section need not extend more than 2½ feet from the free edge of the slab.

The average maximum stress at the extreme edge of these sections of constant thickness is approximately 60 percent greater than the average maximum stress in the interior portions under the given load.

Sections 5, 2, and 1 have thickened-edge cross sections of a similar type, the interior area of each being of a constant thickness. The maximum stress diagrams for these sections (fig. 8) give direct evidence on the reduction in the maximum edge stress resulting from various degrees of edge thickening. Although a definite reduction is apparent for all three of these sections it is indicated that in none of them is the relation between edge and interior thicknesses proper for a constant maximum stress value. It will be noted that the 9–6–9 section is the most nearly balanced, yet even with an edge thickness that is 50 percent greater than the interior thickness, the load placed 6 inches from the extreme edge of this section produced a maximum stress somewhat greater than that caused by the same load applied in the interior of the slab.

EDGE THICKENING FOR BALANCED DESIGN DETERMINED

The relation between edge and interior stresses in the slabs of constant thickness and in the three thickened-edge sections just mentioned provides a means for estimating the extent to which the edge thickness should be increased if a perfect balance of the cross section is to be attained. In figure 10 the increase of edge stress over interior stress (expressed as a percentage of the latter) has been related to the increase of edge thickness over the interior thickness, similarly expressed, for each of these sections. In the case of the four constant thickness sections the average value was used. By drawing a straight line through the plotted points and prolonging this line a short distance to the horizontal axis of the graph, the intercept on this axis indicates approximately the percentage of increase in edge thickness that would be required to reduce the edge stress to the same value as the interior stress.

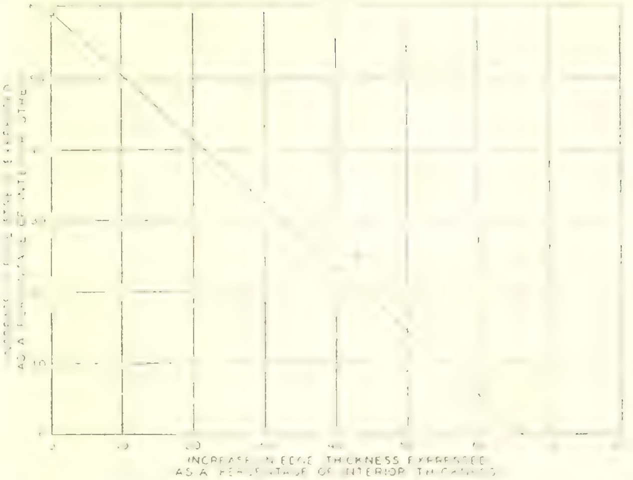


Figure 10.—Effect of Edge Thickening on the Reduction of Edge Stress.

It will be observed that this method of analysis indicates that, for the type of cross section in which the interior of the slab is of constant thickness and the edge thickening is developed at a uniform rate in the outer 2 or 3 feet of the pavement, the thickness of the extreme edge must be about one and two-thirds times that of the interior of the slab, if the section is to be completely balanced for stresses caused by load.

This relation would not necessarily hold for other cross sections of radically different shape and might be affected somewhat by the conditions of subgrade support.

Section 4 has a cross section bounded by two parabolic curves with a thickness of 6.3 inches at the longitudinal joint and 9 inches at the free edge. The maximum stress diagram for this section shows a slightly greater stress at the edge of the slab than at the interior but there is a section at a short distance from the edge in which the stresses are definitely lower than those in the interior of the panel (see fig. 8). The diagram indicates, therefore, that at the extreme edge the section is not of sufficient thickness to balance completely the edge and interior stress values, and that at a short distance from the edge the section is thicker than is necessary. It must be concluded that so far as stress from applied load is concerned this section is not well balanced.

Section 3 has the same center and edge thicknesses as section 4 but the shape of the cross section is quite different. In section 3 the 9-inch edge thickness is maintained in the outer 2 feet and then reduced to the center thickness of 6.3 inches in the next 2 feet of the cross section. The remainder of the slab width is uniformly 6.3 inches thick. The maximum stress diagram for this section shows that the maximum

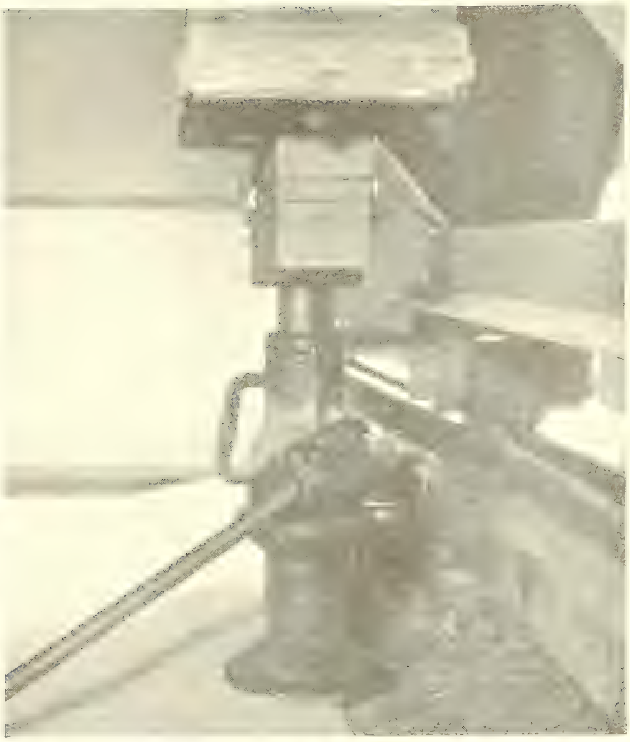


FIGURE 11.—APPLICATION OF A TEST LOAD ON THE EXTREME EDGE OF THE LIP-CURB SECTION.

stress at the free edge is approximately the same as that in the interior of the slab. That part of the cross section at a short distance from the edge is shown to be much stronger than either the edge or the interior and it is this part of the cross section that throws the design out of balance. The diagram also indicates that the heavy edge of this section exerts an influence on the magnitude of the stresses for a short distance beyond the point where the edge thickening is discontinued. The contrast between the deflection diagram (fig. 7) and the stress diagram (fig. 8) for this section is worthy of note. From the deflections it might be concluded that this section was the most nearly balanced of all of those tested, while the stress diagram leads to the conclusion that this section is not well balanced and therefore the most economical use is not made of the material in it.

The stress diagram for section 3 was compared with those for section 4 and the three sections in which the edge thickening was decreased at a uniform rate from the edge of pavement inward (secs. 5, 2, and 1) and it was found that the shape of the cross section has some influence on the relation between the edge and interior thicknesses necessary to balance the maximum stresses for a given load. For example, it has been noted that with the type of cross section represented by sections 5, 2, and 1, an increase in edge thickness of approximately 66 percent over the interior thickness is necessary to balance these stresses, whereas in section 3 an essential balance of edge and interior stresses is obtained with an edge thickness that is only 43 percent greater than that of the interior of the slab. This is undoubtedly due to the greater stiffness of those designs in which the edge thickness is not decreased rapidly from the edge of the pavement, designs which the stress diagrams show to be poorly balanced elsewhere.

SPECIAL METHODS OF LOADING LIP-CURB SECTIONS DESCRIBED

Section 8 was provided with a lip curb on either edge. As mentioned earlier, the two halves of this section, divided longitudinally, are of different design. One half, marked section 8A on figure 1, is of uniform thickness except where the lip curb was added, while on the other half, marked section 8B on figure 1, the lip curb was added to a 9-inch edge, 7-inch interior-thickness cross section. Thus section 8A may be considered as being thickened on the top and section 8B on both bottom and top.

In making tests at the extreme edge of these sections it was necessary to place loads and to measure strains in a manner slightly different from that used on the other sections, because of the presence of the lip curb. The bearing block used was solid, i. e., there was no groove in the bottom, and it was placed on top of the curb, the center of the block being in the center of the level section of the curb, as shown in figure 11. Since this level section is only 3 inches wide, the full area of the bearing block was not in contact with the pavement, and in this position the center of the loaded area was somewhat closer to the edge of the slab than was the case with the other sections. It was considered that this method of loading was justified as it represents the condition of a wheel load "riding" the curb.

The longitudinal strains were measured by installing the two strain gages on the vertical face of the edge of the pavement, one as near the upper and the other as near the lower surface of the pavement as possible.

For reasons that are obvious, it was not practicable to measure the strains in the transverse direction directly under the load when the load was placed at the edge of the lip-curb section. The transverse stress computed from the transverse strain was found to be practically zero at the edges of all of the other sections, so it was assumed to be zero at the edge of the lip-curb section. Consequently, in order to complete the transverse-stress curve for this section, the value plotted represents the transverse effect of the longitudinal stress. All of the other values shown in the stress diagrams are the direct result of strain measurements.

The maximum stress diagram for section 8A shows a slightly higher stress at the edge than at the interior and a slightly lower stress about 18 inches from the edge. Across the remainder of the section the stress is practically constant. It appears that, except for loads applied at the top of the lip curb, this design can be considered as balanced and, since with a lip curb in normal service the application of loads on the top of the curb would probably occur but rarely, it appears that where a lip curb of this design is used no other edge strengthening is necessary. The maximum stress diagram for section 8B confirms this conclusion. It will be seen in figure 8 that, in that part of the cross section which includes the thickening on the bottom of the slab, the stresses are consistently less than in the interior.

It might possibly be argued that, in spite of the fact that the very presence of a lip curb tends to keep the wheel loads away from the edge of the pavement, the section should provide fully for this occasional loading. If such a design is desired, the data indicate that the cross section, exclusive of the lip curb, should be made slightly thicker at the edge than at the interior although not to the same extent as in section 8B. It is probable that an additional inch at the edge, decreased to zero at from 12 to 18 inches from the edge, would accomplish the desired result.

As previously remarked in the discussion of section 3, there is a marked difference between the deductions concerning the relative balance of designs that might be made from the maximum deflection diagrams and those that might be made from the maximum stress diagrams. The deflection data might be taken to indicate that all of the sections are very poorly balanced, while the stress data show that a number of the sections are fairly well balanced. The reason for the difference is that for a given loading the maximum stress is found where the change in the rate of curvature of the elastic curve is greatest and is a highly localized condition, whereas the maximum deflection noted may be the result of deflection over a large area and thus may not be associated with a marked change in the shape of the elastic curve.

This is one of a number of instances in these investigations in which the relations indicated by the deflection data are not in agreement with those shown by the stress data, and in all of the analyses which have been made much more weight has been given to the stress data since the latter are a direct measure of the load-carrying ability of the slab. It is believed that the deflection measurements are, in all cases, as accurate as it is possible to make them by direct methods and that the data show very closely the relative movements which occurred. However, the shapes of the elastic curves of the deflected slabs are not determined by these methods with sufficient precision to warrant any deductions from the deflection data regarding the stress conditions associated with the deflection.

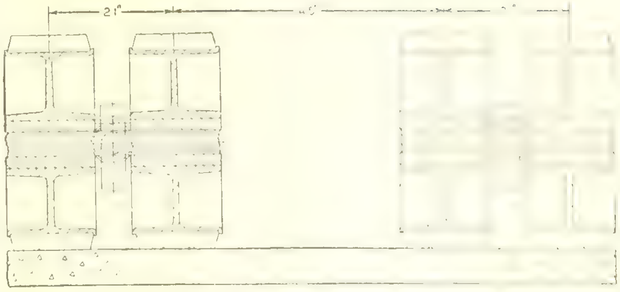
EFFECTS OF MULTIPLE-WHEEL LOADINGS DISCUSSED

The data and discussion thus far presented have related solely to the effects produced by a single load. It has been shown by these and by earlier studies[9] that the area of a pavement slab that is stressed by a single load is relatively small, and the data indicate that if several loads are applied simultaneously, as would occur in the case of a vehicle on the pavement, the critical stress under each load will not be increased by the presence of the other loads, providing the distance between the loads is approximately 3 to 4 feet or more. Thus it is to be expected that 4- and 6-wheel vehicles of the usual types will not have wheel loads so closely spaced that the effect of adjacent wheel loads on stress need be considered. On rare occasions, however, pavements are subjected to heavy loads on closely spaced wheels as, for example, where such cargoes as power shovels, road rollers, electrical transformers, or other concentrated weights are moved over the highway on what are generally known as heavy-duty trailers. These trailers are usually equipped with four wheels at the rear articulated in order to distribute the load to the pavement uniformly.

Figure 12 shows typical wheel spacings (along a plane through the rear axle) for two trailers of the type referred to. It will be noted that the close spacing of the wheels may possibly affect the critical stress in the pavement. Thus, this type of loading might have an influence on the design of the cross section of pavement slabs for certain locations.

No direct tests to determine stresses in the test sections under multiple loadings have been made up to the present time. However, data developed in the tests which have been described in this report furnish a means for investigating the probable effect of loadings such as are shown in figure 12. It was thought that an analysis of these two cases, from the standpoint of a possible influence on the design of the slab cross section, would be of value in the present discussion.

TRAILER LOADING "A"



TRAILER LOADING "B"

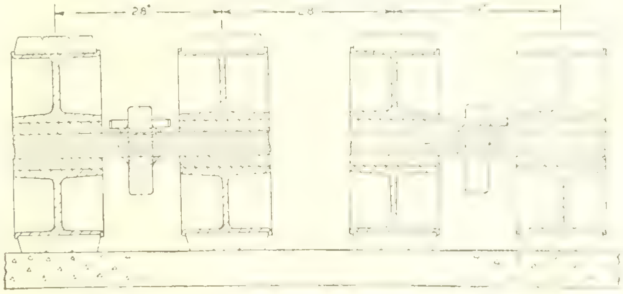


FIGURE 12.—TYPICAL WHEEL ARRANGEMENTS FOR HEAVY-DUTY TRAILERS.

In the description of the testing procedure it was stated that a load was placed successively at each of the points shown in quadrant 4, figure 2, for deflection measurements, or in quadrant 1 for strain measurements, and that the deflection or strain was measured at each of these points for every position of the load. From the data obtained it is possible to construct diagrams that show the variation in deflection or stress at any one of the points of measurement as the point of loading was moved transversely across the slab. These diagrams are in reality influence lines for deflection or for stress for the several points along the cross section.

Taking again the 6-inch uniform-thickness slab (sec. 10) and the 9-6-9 thickened-edge slab (sec. 5) as representative sections, influence lines for deflection for each of the 7 load positions in quadrant 4 are shown in figure 13, and corresponding influence lines for stress for each of the 10 load positions in quadrant 1 are shown in figure 14. These values are for a 5,000-pound load applied on a circular area 8 inches in diameter.

It was mentioned earlier in this paper that the structural action of the longitudinal joint exerted an influence on the magnitude of the stresses produced by a given load and that the effect might extend as far as 3 feet from the joint. For this reason the data taken within this distance of the joint have been omitted generally from the figures. An exception was made in the case of the influence lines because it is believed that they will be more useful if shown in this way. The values given for points within approximately 3 feet of the longitudinal joint apply strictly only to those designs that include longitudinal joints having the same structural

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[9] See The Six Wheel Truck and the Pavement, by L. W. Teller, PUBLIC ROADS, vol. 6, no. 8, October 1925. Also see Stresses in Concrete Pavements Computed by Theoretical Analysis, by H. M. Westergaard, PUBLIC ROADS, vol. 7, no. 2, April 1926.

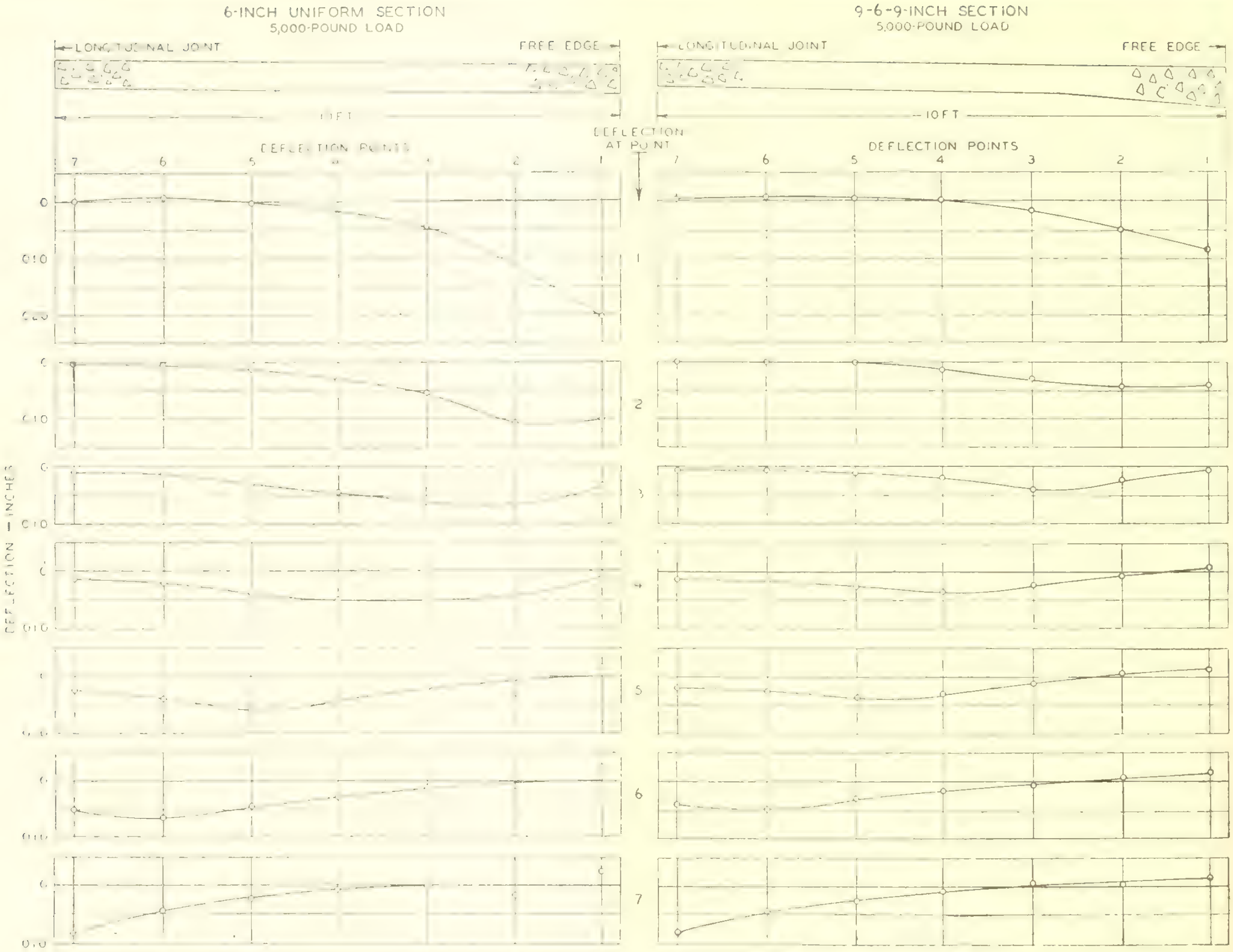

Figure 13.—Influence Lines for Deflection on Two Typical Sections.

action as those used in the tests, but should apply with reasonable accuracy for other designs of a similar type and degree of joint efficiency.

The longitudinal joint of section 10 is a corrugated steel plate, with ½-inch diameter deformed steel bars in bond and placed transversely at 60-inch intervals. The longitudinal joint for section 5 is a steel plate with a single triangular tongue with steel bars placed in the same manner as in section 10. In tests of the efficiency of the longitudinal joints of the various sections it was found that both of the joints described were of approximately the same efficiency and that both were fairly efficient. It is believed that the data shown will apply with a reasonable degree of accuracy to longitudinal joints of the tongue type where longitudinal continuity is provided. If the longitudinal joint is of a different type then only the values for the outer 7 feet of the cross section apply.

The magnitude of the stresses developed in a concrete pavement slab by a load is affected by the type and character of the subgrade as well as by the elastic properties of the pavement. The absolute values of deflection and stress shown in these diagrams apply only to the particular conditions of the tests. However, as has been said before, the subgrade conditions for the tests at Arlington might well be considered as average and it is believed that the influence lines as developed in these tests should give a good general indication of the effects of different types of loading on pavement slabs.

MAXIMUM STRESS DIAGRAMS FOR MULTIPLE-WHEEL LOADINGS DEVELOPED

From the influence lines for stress, stress-variation curves, similar to those shown in figure 6 but for the particular load positions desired, were constructed for each of the four wheel loads of the two types of trailer. These are shown as light solid lines in figure 15, and since they are all longitudinal stresses they may be combined as in the heavy solid lines to show the stress variation along the pavement cross section under the influence of the four loads applied simultaneously. The light dotted lines indicate the general shape of the enveloping curves, or maximum stress diagrams, that might be expected should this combination of loads be shifted transversely across the section. It should be noted that the curves in this figure are for the 6-inch uniform-thickness section.

For the type of loading designated as "A" (fig. 12) the diagram shows that the interior stress has a constant value to within approximately 3 feet of the free edge of the pavement, and that the maximum edge stress is about 50 percent greater than the interior stress. This differs but very little from the conditions

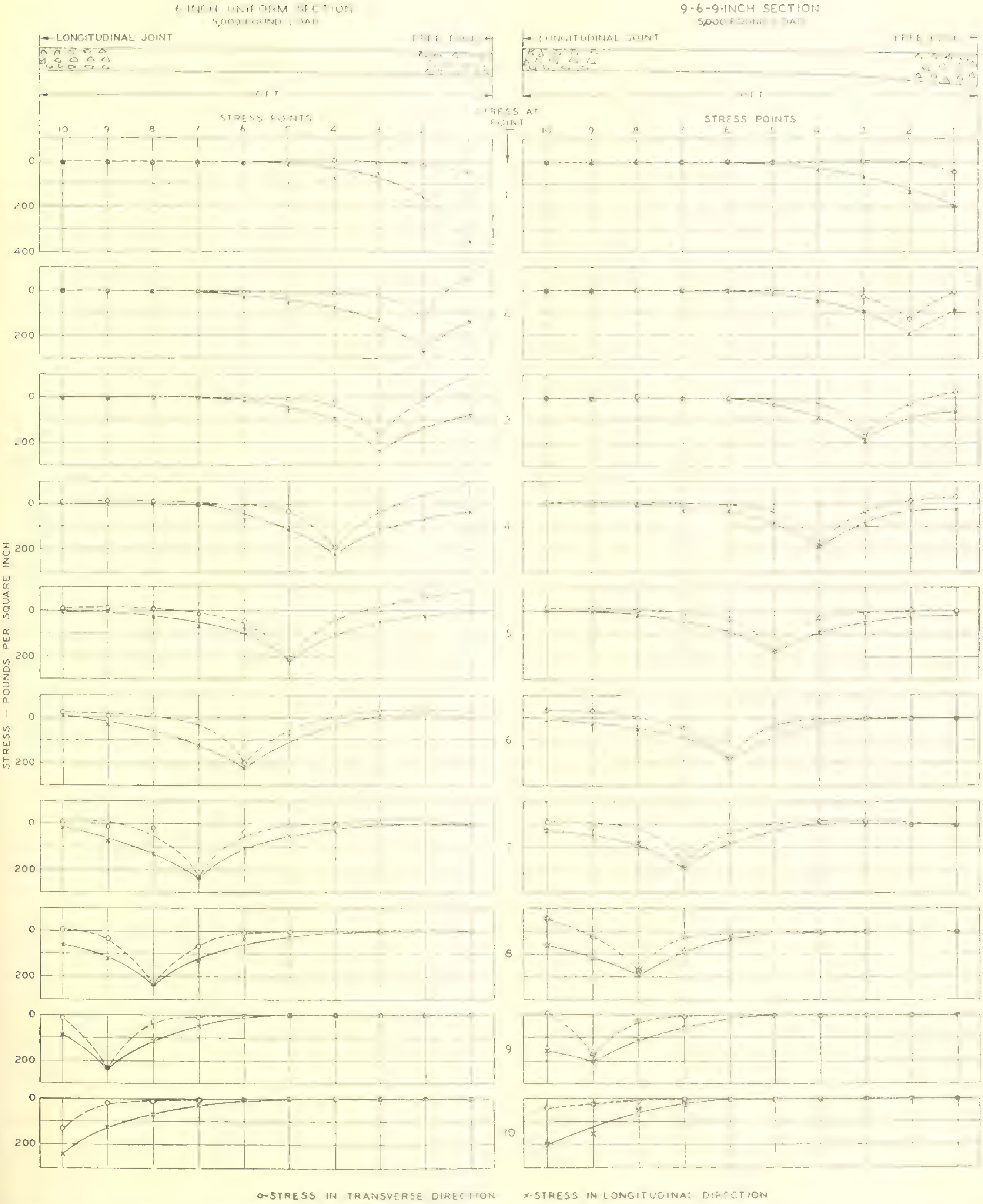

FIGURE 11.—INFLUENCE LINES FOR STRESS ON TWO TYPICAL SECTIONS. VALUES ABOVE THE AXIS INDICATE TENSION, AND VALUES BELOW THE AXIS INDICATE COMPRESSION IN THE UPPER SURFACE OF THE SLAB.

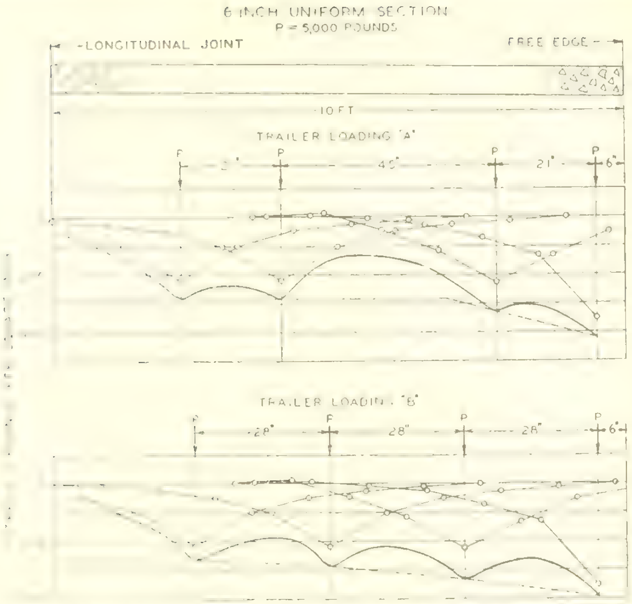

FIGURE 15.—CONSTRUCTION OF MAXIMUM STRESS DIAGRAM FOR TRAILER LOADINGS—OUTER WHEEL OF TRAILER NEAR FREE EDGE OF SLAB.

developed under the single loading, from which it seems reasonable to conclude that a section designed for balanced stresses under single or widely separated loads would prove to be reasonably well balanced under the trailer loading "A."

For a loading of the type designated as "B" the stress conditions are slightly different due to the greater separation and more uniform distribution of the loads. For the same total load the critical stresses are slightly lower than they were for loading "A" and the stress decreases across the full width of the loaded area from the edge toward the center. Again the maximum or edge stress is about 50 percent higher than that developed in the interior of the panel. If a section were to be designed especially for this type of loading, the analysis indicates that it would be economical to extend the edge thickening toward the center of the pavement more than is necessary when designing for conventional types of loading. However, it is indicated again that a pavement balanced for single loadings will also be reasonably well balanced for trailer loads of this type.

In the above analysis the outer load was centered 6 inches from the edge of the pavement. This is an extreme condition and not likely to be encountered in the moving of very heavy loads. It is of interest to make a similar study for the more probable condition of the center of the load group being coincident with the center of the 10-foot slab width. In making this analysis the 9–6–9 thickened-edge section (sec. 5) was used, since this is a fairly well-balanced section and one which is widely used.

The stress variation curves for both trailer loadings on this section are shown in figure 16. These curves were developed in exactly the same manner as those in the preceding figure.

It appears from this diagram that on this cross section the maximum stresses under the four loads are of practically equal magnitude. It is also indicated that at these four critical points the stress developed by the multiple loading is about 30 percent greater than under the single load.

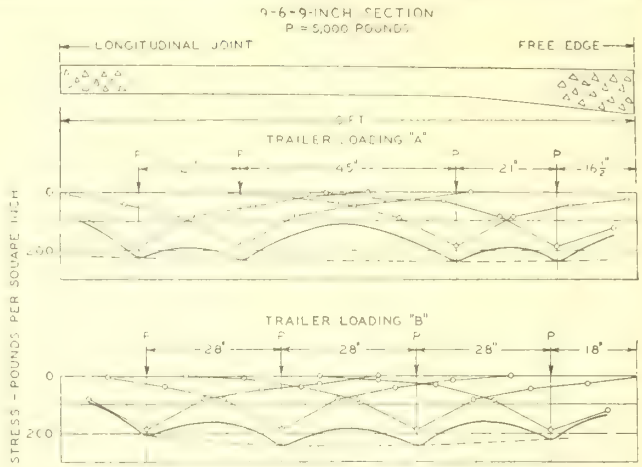

FIGURE 16.—CONSTRUCTION OF MAXIMUM STRESS DIAGRAM FOR TRAILER LOADINGS—CENTER OF TRAILER OVER CENTER LINE OF SLAB PANEL.

This means that 5,000-pound wheel loads distributed in this manner would cause critical stresses some 30 percent higher than would single or more widely separated wheel loads of the same magnitude.

As stated at the beginning of this discussion of multiple-wheel effects no direct tests of such loadings have yet been made nor have the relations between stresses developed under an 8-inch diameter circular bearing block and those under various types and sizes of motor-vehicle tires been established. For these reasons the data should not be extended too far and the analysis should be considered indicative rather than conclusive.

There is another factor involved in an evaluation of multiple-wheel loading concerning which no data are available. When a single load is placed on a pavement slab and a certain maximum stress is developed, this maximum stress extends over a distance approximately equal to the diameter of the bearing area and then diminishes rapidly. For trailer loadings of the type described the maximum stress value obtains over a much greater percentage of the pavement width, and whether or not for a given stress value its effect on the slab is more severe has not been established.

In the preceding paper the importance of the stresses caused by restrained warping was pointed out. If heavy loads are to be moved on trailers having closely spaced wheels, consideration should be given to the possibility of over-stressing the pavement through a combination of warping stresses and load stresses. It may be desirable to confine the movement of certain types of heavy vehicles to those parts of the day when warping stresses are lowest, i. e., at night or in the early morning.

CRITICAL STRESSES RESULTING FROM LOAD NOT GREATLY AFFECTED BY SLAB WARPING

In the first part of this paper attention was called to certain effects of temperature that may influence the load-stress relation in concrete pavements, and it was stated that in this investigation consideration was given to the following:

1. The effect of the condition of warping on the stresses caused by applied loads.

2. The effect of the changes in the supporting power of the subgrade caused by freezing and thawing or by other causes.

3. The stresses caused by variations in the temperature of the pavement.

In the following paragraphs the significance of the data obtained with respect to the design of the cross section will be discussed.

One of the important effects of temperature changes on a concrete pavement is that temperature differentials are developed which cause marked changes in the shape of the slab. Since this results in a modification of the condition of support, it affects the magnitude of the stresses caused by a given applied load, as was brought out in part 2 of this series of papers.

In studying the design of a pavement cross section some consideration should be given to the changes in the load-stress relation caused by slab warping in order to determine what correction, if any, should be applied to basic data obtained from pavement sections tested in a flat or unwarped condition.

A study was made of the effect of both upward and downward warping on the load-stress relation and these data were presented and analyzed in part 2. It was shown that the effect of slab warping on the magnitude of the stresses caused by load was negligible in the interior portion of the slab panel. In figure 35 of part 2 it was shown that:

1. Maximum downward warping reduced the critical stresses caused by load at the edge of the pavement by about 6 percent in the 7-inch slab (sec. 9) and about 2 percent in the 9-inch slab (sec. 6).
2. Maximum upward warping increased the critical stresses caused by load at the edge of the pavement by about 8 percent in the 7-inch slab and about 20 percent in the 9-inch-slab.

From these data it would be concluded that it is not necessary to make any correction to the load-stress relation at the interior of the section, but that small adjustments of the critical stresses at the outer end of the cross section may be desirable to compensate for the effects of slab warping.

FREEZING AND THAWING OF THE SUBGRADE PRODUCES CONSIDERABLE EFFECT ON STRESSES

In part 2 there was included a description of certain load tests conducted during a period of freezing and thawing of the subgrade and a rather full discussion of the effect of the condition of the subgrade on the load-stress relation was given. This is a matter having possible bearing on the design of pavement cross sections and it is pertinent to reexamine the data with this in mind.

It will be recalled that at the time of these particular tests the subgrade was at first frozen solidly to a depth of 2½ inches under the pavement and to a depth of 7 inches below the surface of the earth shoulder, and that later it thawed rapidly until near the surface it became very wet and completely plastic. During the time that the earth was frozen, the pavement sections were displaced upward or heaved about one-half inch.

The conditions of pavement support are probably more uncertain during the period immediately following a thawing of the subgrade than at any other time. For this reason stress data obtained after a thaw are of more importance than those obtained with the subgrade in the frozen state.

Figure 17 shows the maximum stress diagram for section 5 (9–6–9 cross section) under a 7,000-pound load with the subgrade in a softened condition immediately after a thaw. The values shown are the averages of two sets of strain measurements.

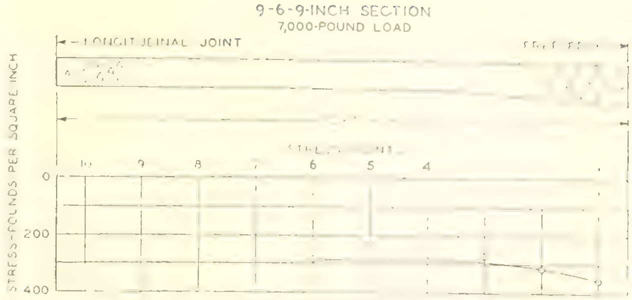

FIGURE 17.—MAXIMUM STRESS DIAGRAM FOR ONE OF THE TEST SECTIONS WITH THE SUBGRADE IN A SOFTENED CONDITION IMMEDIATELY AFTER A THAW

The maximum stresses at the various points in the interior of the slab are much less uniform than they were found to be with the subgrade in its normal condition. (See fig. 8.) The lack of uniformity in the stresses is probably the reflection of a similar lack of uniformity in the physical condition of the subgrade. Also the stresses for a 7,000-pound load (fig. 17) are of approximately the same magnitude as those shown for the 8,000-pound load (fig. 8).

It will be noted that the curve showing the variation of maximum stress across the section has been drawn through the maximum stress values rather than as an average of all the values. This was done deliberately so that the relation between edge and interior stresses as shown by the diagram for the condition of a thawing subgrade would represent the most critical value developed by these tests. As the curve is drawn the maximum edge stress is approximately 25 percent above the value of the maximum stress at the interior. This is practically the same relation as was found in other tests during the winter months when the subgrade is wet, so it appears that, for this section at least, it might safely be assumed to be representative of winter conditions. For the remainder of the year the relation between edge and interior stress is as shown in figure 8.

COMBINED LOAD AND TEMPERATURE WARPING STRESSES DISCUSSED

When the temperature of the pavement changes two effects are produced. First, there is a change in the average temperature of the concrete; and second, there is almost certain to be a change in the relation between the temperatures of the upper and lower surfaces of the slab.

The first effect changes the dimensions of the slab and, because there is a resistance to horizontal movement developed in the earth of the subgrade, direct tensile or compressive stresses (depending upon the direction of movement) are created, which attain their maximum value in the mid-section of the slab. The unit stresses developed in this manner are normally of the same magnitude across the entire width of any given section and for this reason do not enter as a factor in the design of the cross section. Their principal influence is a general increase or decrease in the amount of stress resistance that is available for carrying wheel loads.

The stresses developed as a result of restrained warping under the action of a temperature differential (the second effect mentioned above) are of more importance than the direct stresses described in the preceding paragraph, because at certain times they may be of considerably greater magnitude, but more particularly because they vary in magnitude from point to point

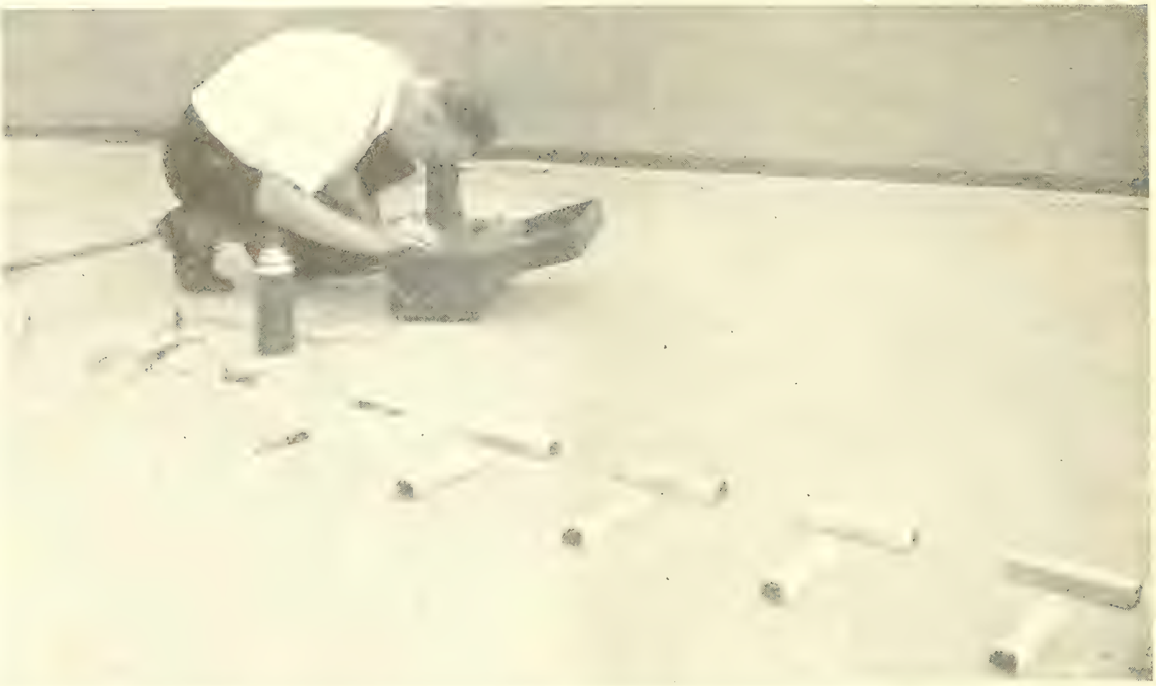

Figure 18.—Arrangement of Recording Strain Gages and Thermocouple Equipment for Studying the Stresses Caused by Restrained Temperature Warping.

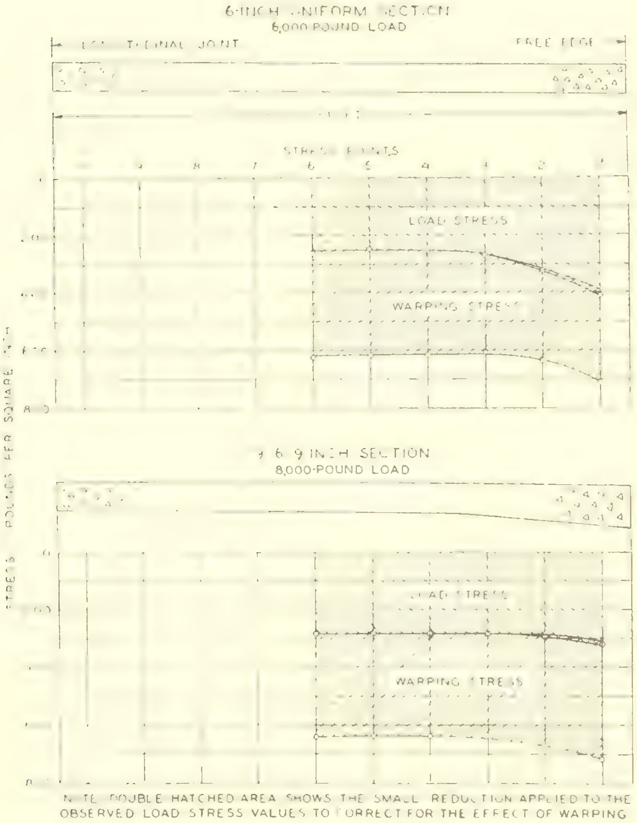

Figure 19.—Maximum Stress Diagrams for Combined Load and Warping Stresses for Two Typical Cross Sections. The Double-Hatched Area Shows the Small Reduction Applied to the Observed Load Stress Values to Correct for the Effect of Warping.

across a given section. It is desirable, therefore, to examine these stresses as they combine with the stresses caused by applied loads in order to determine their influence on the design of the cross section.

The stresses resulting from restrained warping were not determined for all of the test sections, but the data for one constant-thickness section and one of the thickened-edge sections will be given as typical examples. The two sections selected were the 6-inch constant-thickness section (sec. 10) and the 9–6–9 thickened-edge section (sec. 5). The technique employed in these tests has been described in part 2 and a typical installation of the apparatus is shown in figure 18.

Figure 19 shows the maximum stress diagrams for these two sections and the stress values shown are the result of restrained warping and applied load combined. The load stresses are those shown in figure 8, while the warping stresses are average maximum values as determined by measurement during the spring and summer months when the temperature warping is at a maximum, as shown in figure 35 of part 2.

It was not possible to measure the warping stresses on the sections having thickened edges in the usual manner, due to the difficulty of measuring the change in length which should occur in the interior of the slab for the condition of free warping. It is probable, however, that the warping stresses for the 9–6–9 section approximate in magnitude those of the 6-inch uniform-thickness section except in the vicinity of the edges. It was shown in part 2 that the average warping stresses at the edge of the 9–6–9 section are approximately 30 percent above those at the edges of the 6-inch section of constant thickness, and this relation has been used to establish the warping stress at the edge of the 9–6–9 section in figure 19.

Since the load stresses near the edge are reduced slightly by the same downward warping of the edges that produces the critical warping stresses, a slight correction has been applied to the load stress values in this diagram. The correction was made in accordance with the experimental data on this point previously referred to.

The curves in figure 19 for the maximum combined stress across the two typical pavement sections show a very uniform stress condition throughout the interior area of both sections. Since the interior of both of these sections is of constant thickness, it is indicated that for a balanced cross section the interior of the slab should be of a constant thickness. This was shown to be the requirement when only the stresses developed by applied loads were considered. The shape of the interior portion of the cross section is the same, therefore, whether determined by load stresses alone or by combined stresses.

Referring to the diagram for the 6-inch constant-thickness section in figure 19, it will be seen that the combined stress at the edge is about 90 pounds per square inch, or 15 percent above that in the interior. This compares with an increase of 165 pounds per square inch or 60 percent where load stresses only are considered (see fig. 8), and the comparison indicates that when the combination of the stresses from restrained warping and from applied loads is considered, the pavement of constant thickness is more nearly balanced than it is for the stresses from applied load alone. In order to balance the combined stresses for this section it would be necessary to reduce the edge stresses by slightly more than one half of the amount that would be necessary to balance the load stresses only.

For the 9–6–9 section, the diagram in figure 19 shows that combined stress at the edge of the pavement is about 85 pounds per square inch or 13 percent above the interior stress. This is practically the same relation as was found to exist in the slab of constant thickness and indicates that so far as maximum combined stresses across a mid-slab section are concerned, the 9–6–9 section is no better balanced than the section of constant thickness. This somewhat startling result is explained by the fact that the increase in the warping stress at the edge of the thickened-edge slab, caused by the increased temperature differential which results from the greater depth, is approximately equal to the reduction in load stress at this point accomplished by the increased edge thickness.

SHORT SLAB LENGTHS NEEDED TO MINIMIZE STRESSES CAUSED BY TEMPERATURE WARPING

It has been shown, during the discussion of warping stresses in part 2, that the magnitude of the critical warping stress that most directly affects the load capacity of the pavement is a function of slab length. The data show that in a slab length of 10 feet the maximum warping stresses are small but that they increase with length until the length is such that complete restraint to warping exists in the interior of the slab. The length necessary for complete restraint in slabs of different thicknesses has not been determined in this investigation. It is indicated that practically complete restraint is developed by a 20-foot length in a slab of 6-inch constant thickness, and also that this length in a 9–6–9 thickened-edge section is not sufficient to develop full restraint at the mid-length of the panel.

Because of the effect of slab length, it is apparent that the analysis of combined stresses given above can be applied exactly only to slab lengths of 20 feet.

It is not known whether the stresses caused by load in the test sections are larger or smaller than those developed in actual pavements by traffic, so that the comparison between the combined stresses observed in the test sections and the combined stresses that occur in pavement slabs in service is not certain. It is apparent, however, that in pavement slabs as they are designed today the factor of safety against breaking must be very small at times when conditions are such as to produce high warping stresses. The relatively frequent transverse cracking in our more heavily traveled concrete pavements is also an indication that the combined stresses in them often exceed the flexural strength of the concrete.

At first thought one might expect immediate cracking when the combined stresses exceeded the strength of the concrete, and this would probably occur if the high stresses extended completely across the slab. When the critical stress is highly localized, as it appears to be under an isolated load, a single application of an excessive stress may produce no immediate effect. In cases where load stresses are responsible either wholly or in part for the cracking of a pavement, it is but natural to expect the transverse cracking to develop gradually and to continue over a period of years.

Consider, for example, the case of a heavy wheel load moving longitudinally on the pavement at a time when high warping stresses are present in the slab. Being of the same sense in the mid-section of the slab, the stresses combine and may exceed the ultimate flexural strength of the concrete. These tests indicate that the high combined stress will be found to exist only for a very short distance directly under each wheel. The remainder of the cross section will not be overstressed. It is not probable that such a stress condition would cause a full-length transverse crack immediately, but it is reasonable to believe that a great many repetitions of the condition would cause such a crack.

If the length and width of a pavement slab were equal, the warping stresses would be the same in the two directions and it would be reasonable to expect the added stress caused by wheel loads to cause longitudinal cracking to precede transverse cracking, because the wheel load traverses the complete length of the slab, stressing every point in the longitudinal section, yet this wheel stresses to the same degree only a comparatively small part of any traverse section. This may explain the early appearance of longitudinal cracks in some of the older pavements that were built without a longitudinal joint.

In concrete slabs where the combination of the length, depth, and flexural strength are such that warping stresses alone may cause the slab to crack, it is to be expected that such cracks will develop suddenly, since the high stress condition extends over the entire cross section.

SHORT SLABS MAY BE DESIGNED ON THE BASIS OF LOAD STRESSES ALONE

Before proceeding with a discussion of the application of the results of the investigation to the design of a pavement cross section, it may be well to review briefly some of the points developed in parts 1 and 2.

It has been demonstrated conclusively that variations in the temperature of the concrete in the pavement slab frequently cause large stresses in certain parts of the slab. These stresses combine with those caused by applied loads, and the pavement design, to be adequate, must be based upon combined stresses rather than upon load stresses alone.

It will be recalled that loads were applied with the test sections in the flat condition and in the warped condition and that tests were made when the subgrade was in its normal condition of moisture and also at a time of excessive moisture immediately after a thaw. Data were presented to show the influence of concrete temperature on (1) the direct stresses resulting from the resistance offered by the subgrade to horizontal slab movement, and (2) the bending stresses caused by restraint to free warping which exist in practically every part of the slab.

Since the magnitude of the stresses caused by a given applied load is affected by the warping of the slab to a certain degree at the edge of the slab and to a different degree at the interior, it is evident that this is a factor that must be considered.

It was shown in figure 17 that the relation between edge and interior stresses is practically the same during the very wet conditions that prevail immediately after a thaw as during the balance of the winter. Many of the tests that supplied the data for the maximum stress diagrams were conducted during normal winter conditions. It is believed to be unnecessary, therefore, to make an allowance for subgrade condition in setting the ratio of edge to interior thickness.

The usual assumption concerning the direct stresses of tension or compression, caused by the resistance to horizontal movement offered by the subgrade, is that they are uniform over the full cross section of a slab of constant thickness. It is probable that the same assumption could be applied to the thickened-edge sections of this investigation with no great error. If this is assumed to be the case, the stresses referred to will not affect the shape of the cross section.

The effect of closely grouped wheel loads was investigated to a limited extent, and the maximum stress diagrams which were developed indicate that the shapes of the load-stress curves for the multiple loads are approximately the same as for single loads. This leads to the tentative conclusion that a cross section designed for single loadings will not need to be modified because of multiple loadings of the type described.

In order to design a cross section from the maximum stress diagrams shown in figure 19 it will be necessary to make allowance for the following:

1. The effect of the condition of warping on the stresses caused by loads applied along the cross section of the slab.
2. The stresses caused by the restrained warping resulting from temperature differentials within the slab.

The stresses caused by restrained warping are dependent in magnitude upon the length and the thickness of the pavement slab and this must be considered in a discussion of the design of the cross section. It was shown in table 5 of part 2 that if the length of slabs of the usual pavement thicknesses is reduced to approximately 10 feet, the maximum stresses caused by restrained warping are quite small. The difference between the warping stress at the edge and that at the interior points is reduced to such an extent as to be unimportant in its effect upon the design of the cross section. If a pavement slab were to be deliberately designed with a length of 10 feet, it would be sufficient to design the cross section on the basis of load stresses alone.

The maximum stress diagrams shown in figures 8 and 9 will be used to design a balanced pavement cross section with the slab length limited to 10 feet. The principal decisions to be made are:

1. What should be the shape of the interior portion of the cross section?
2. What should be the relation between the depth of the slab at the interior where the conditions of support are most favorable and the depth at the free edge where they are the least favorable?
3. What should be the shape of the cross section near the free edge?

It is definitely indicated by all of the data and shown more clearly by the average curve for the four constant-thickness sections that, except in the immediate vicinity of the slab edge, the pavement slab should be of uniform thickness (see fig. 9).

A load applied at an unsupported edge causes a maximum stress considerably higher than that produced by the same load placed at interior points of the slab. Designing for balanced load stresses therefore requires a strengthening of free slab edges. The degree of thickening required for this strengthening can be determined from figure 10, which indicates that the depth of the slab at the free edge should be one and two-thirds times the depth in the interior region. As mentioned before, this ratio applies only to cross sections in which the additional or edge thickening is reduced to zero approximately uniformly between the edge and a point a short distance from the edge.

The distance in which this reduction of edge thickness should be accomplished is determined by the variation in the stresses in the longitudinal direction since these are the critical load stresses in the vicinity of the edge. The average curve for stress for the four constant-thickness sections (see fig. 9) shows that the interior stress is practically uniform from the center out to a point approximately 2½ feet from the edge, and indicates that for this area no additional depth would be required. The data also indicate that the effect of the thickened edge on the maximum stress from load is felt even beyond the point at which the thickening ends. Considering the stress diagrams for all of the sections, it seems reasonable to conclude that the edge thickening need not extend more than approximately 2 feet from the edge. Again this applies only to the type of cross section in which the edge thickness is reduced to the interior thickness at an essentially uniform rate, as in section 5. While the data obtained with the test sections of this type indicate that this is probably the minimum distance over which the edge thickening should be reduced, as a practical matter in shaping the subgrade the tendency will be to increase rather than decrease this dimension. In balancing the cross section for load, it is probably permissible to adopt the minimum distance, or 2 feet, as this dimension.

TEST RESULTS APPLIED TO THE DESIGN OF A BALANCED CROSS SECTION

It is not to be expected that the data from field tests, no matter how carefully the tests were conducted, would justify fine distinctions as to the shape of the cross section where the edge thickening is introduced. The data indicate quite definitely that the desired balance of stresses is accomplished to a satisfactory degree by a cross section in which the increase in slab thickness is developed at a uniform rate as the edge is approached, as in sections 1, 2, and 5. None of these three sections had an edge depth sufficient to balance fully the load stresses, yet the advantage of this type of edge thickening over that provided in sections 3 and 4 is readily apparent in the maximum stress diagrams.

The pavement cross section shown in figure 20 has been designed in accordance with the principles developed by this investigation, and it represents a section that is completely balanced so far as the stresses from applied loads are concerned. The interior of the cross section is of constant depth and the relation between this depth and that at the extreme edge is 3 : 5 and is constant for the usual range of pavement thicknesses. The difference between the depth at the edge and that at the interior is reduced to zero in a distance of 2 feet.

It is apparent that the design based on these principles is not radically different from that used by a number of States today. However, attention is called to the fact that this design does not take into account temperature stresses and for this reason can be effective only when conditions are such that large temperature stresses will not develop. Climatic conditions so constant as to accomplish this are rare indeed, but as mentioned previously, a very large reduction in the magnitude of the critical temperature stresses can be obtained by using short slabs.

It is indicated by the data presented in part 2 that even with a 10-foot slab length the maximum stresses caused by restrained warping are greater in magnitude than the increase in load stress caused by upward warping of the edges of the pavement. Therefore, the critical combined stresses to be considered in the design of the cross sections are those occuring during the daytime when the edges of the slab are warped downward.

It was assumed earlier that the small difference between the warping stresses at the edge and those at the interior of a 10-foot slab would not cause the relation for combined stresses to be materially different from that which obtained for load stresses alone. In proceeding from the unwarped condition, for which the cross section shown in figure 20 was designed, to that of the combined stresses of the warped slab of the 10-foot length, it is only necessary, therefore, to modify the load stresses slightly due to the effect of the condition of downward warping. It has already been shown that this decrease for a load applied at the edge of the 7- and the 9-inch sections was about 5 percent.

If the edge stresses shown in figure 9 are decreased by 5 percent, it is found that the edge thickness of a balanced slab should be approximately 1.6 times the interior thickness instead of 1.66 as was indicated for the unwarped slab condition. This is a small difference and is perhaps beyond the accuracy of this method for determining the relation between edge and interior thickness. The data do lead definitely to the conclusion that in slab lengths of approximately 10 feet a balanced design requires a maximum edge thickness that is slightly more than one and one-half times the interior thickness.

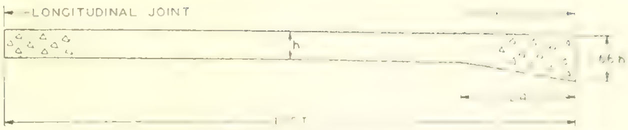

FIGURE 20.—SLAB PANEL CROSS-SECTION COMPLETELY BALANCED FOR LOAD STRESSES

Increasing either slab length or pavement thickness increases the warping stress up to the point at which the length for a given thickness is such that complete restraint to warping exists in the center of the slab. For this reason, increasing the edge thickness of a long slab may not increase the load-carrying capacity of the slab edge as much as would be expected. As shown in the maximum stress diagrams for combined stress in the two 20-foot slabs of figure 19, the benefits derived from the thickened edge from the load-stress standpoint are practically offset in the 20-foot section by the increased warping stresses which unavoidably result. It is conceivable that there may be cases of slabs so long that complete restraint to warping is developed in which the thickening of the slab edge may actually lower the load-carrying ability of the edge.

It may seem from the above discussion that the thickening of slab edges should be eliminated in slabs with lengths of 20 feet or more. So far as strengthening the edge in the mid-length of the slab this is probably true. The high combined stresses in long slabs that carry heavy loads eventually lead to transverse cracking which shortens the slab length and thus reduces the warping stresses and consequently the combined stresses at the edges of the slab.

While the design of slab corners is not discussed in this paper, edge thickening is so intimately connected with corner design that some mention of the effect of edge thickening on the stress conditions in the region adjacent to the slab corner should be included. Thickening the edges of a pavement slab does not increase the combined stresses in the corner because the critical warping stresses are opposite in sense to those caused by load. Edge thickening is effective therefore in reducing the combined stresses at the corner.

This study leads inevitably to the conclusion that a condition of balanced stresses in a pavement cross section is possible only when the critical stresses arising from restraint to warping are definitely limited to low values. The most practical method of insuring this seems to be through the construction of short pavement slabs. Application of this conclusion to the design of pavement slabs involves considerations other than those discussed in this report but necessary to the forming of a correct judgment as to whether or not a completely balanced design should be used or how closely it should be approached.

CURRENT STATUS OF FEDERAL-AID HIGHWAY PROJECTS

(1936 FUNDS ONLY)

AS OF NOVEMBER 30, 1935

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	2,604,320										2,604,320.00
Arizona	1,781,347				1,389,215.53	1,198,466.20	85.7	388,436.65	320,641.34	10.0	262,239.46
Arkansas	2,142,723										2,142,723.00
California	4,756,959				1,197,001.30	693,492.57	12.7	2,103,127.43	1,207,287.26	35.0	2,856,179.17
Colorado	2,288,811				865,168.84	484,509.67	36.1	362,807.16	203,171.98	15.5	1,601,129.35
Connecticut	791,253										791,253.00
Delaware	609,375							342,885.25	171,442.62	34.4	437,932.38
Florida	1,655,723				674,677.71	337,338.85	23.8	218,968.11	109,484.05	8.8	1,208,900.10
Georgia	3,168,221							1,620,894.90	810,483.37	97.0	2,357,737.63
Idaho	1,531,162	168,613.79	100,455.06	32.1	1,142,944.41	671,939.02	107.5	64,241.67	38,442.21	6.0	720,325.71
Illinois	5,160,696				1,488,507.04	744,163.02	35.9	3,532,954.33	1,766,477.09	47.6	2,650,055.89
Indiana	3,087,613				2,567,510.92	1,283,715.72	84.9	2,211,644.45	1,101,783.85	53.1	702,113.43
Iowa	3,231,718	13,228.44	6,300.00	6.6	3,495,891.78	1,641,960.00	195.3	2,112,416.22	995,746.00	88.6	587,712.00
Kansas	3,317,054				99,511.62	49,755.81		932,265.31	466,132.54	159.7	2,801,165.65
Kentucky	2,304,143				1,648,933.15	804,884.09	110.4	1,693,936.82	811,064.07	70.2	688,194.84
Louisiana	1,776,939				602,942.39	301,471.17	21.0	1,262,230.77	631,115.34	46.5	844,352.49
Maine	1,090,167	68,317.53	34,158.76	1.4	1,560,212.03	780,105.94	48.9	182,016.40	91,008.19	3.3	184,894.11
Maryland	1,025,870										1,025,870.00
Massachusetts	1,741,877										1,741,877.00
Michigan	3,837,292	345,600.00	172,800.00	10.3	3,430,900.00	1,712,725.00	141.5	1,712,124.00	856,062.00	66.5	1,095,705.00
Minnesota	3,423,306	334,237.74	143,116.10	12.2	2,194,445.12	944,666.36	127.9	1,310,449.18	523,220.75	86.9	1,812,302.79
Mississippi	2,196,524										2,196,524.00
Missouri	3,800,856	1,013,357.18	506,678.54	190.6	2,242,800.09	1,121,399.92	110.4	1,466,689.62	733,344.70	67.3	1,439,432.84
Montana	2,560,449	306,840.91	171,800.17	106.3	1,241,502.23	695,117.00	119.8	125,245.36	70,124.85	.3	1,623,406.98
Nebraska	2,581,663	383,196.94	191,598.42	36.2	1,353,576.31	676,788.12	98.3	11,827.75	5,913.87	5.2	1,707,362.59
Nevada	1,595,501	121,853.40	105,488.47	55.4	646,152.31	559,374.04	55.1	288,079.30	249,390.25	40.8	681,248.24
New Hampshire	609,375				360,618.09	177,366.44	10.0	472,306.38	232,596.39	10.8	199,412.17
New Jersey	1,675,751				1,106,107.99	553,053.97	20.0	2,172,606.12	1,086,303.03	18.2	36,394.00
New Mexico	1,999,299				1,102,970.24	670,826.37	102.2	275,466.78	167,538.85	27.3	1,160,933.78
New York	6,150,106				5,539,155.47	2,759,800.00	115.9	2,515,750.00	1,221,000.00	35.2	2,169,306.00
North Carolina	2,938,657				1,077,661.89	538,830.86	172.6	140,029.76	70,014.87	25.9	2,329,811.27
North Dakota	1,960,162										1,960,162.00
Ohio	4,565,435				291,762.00	145,782.00	2.1	911,000.00	455,500.00	16.0	3,964,153.00
Oklahoma	2,947,521				580,140.72	304,863.88	14.0	1,277,345.11	671,244.76	48.1	1,971,412.36
Oregon	2,044,633				1,591,996.12	963,984.77	65.1	783,198.35	477,728.97	25.5	602,919.26
Pennsylvania	5,348,062	18,018.35	9,009.17	.6	1,563,645.80	781,822.85	27.1	4,522,062.88	2,260,776.46	58.8	2,296,453.52
Rhode Island	609,375										609,375.00
South Carolina	1,692,896										1,692,896.00
South Dakota	2,036,775				513,132.07	281,244.11	35.2	67,987.31	37,277.38	9.9	1,718,253.51
Tennessee	2,638,159				819,471.58	409,735.76	37.9	453,822.83	226,911.40	17.8	2,001,511.84
Texas	7,777,504				4,189,074.28	2,065,622.41	245.6	2,604,651.30	1,292,788.32	132.2	4,419,093.27
Utah	1,410,752	108,747.96	78,516.02	9.4	664,328.43	479,645.07	54.4	41,334.09	29,843.21	3.2	822,747.70
Vermont	609,375	25,987.44	12,993.72	2.9	1,029,717.75	514,858.82	49.2	117,445.89	58,722.94	6.1	22,799.52
Virginia	2,278,475							613,964.86	306,982.40	23.6	1,971,492.60
Washington	1,949,957	304,340.27	160,400.00	8.9	1,275,216.03	672,000.00	50.1	468,888.97	247,293.19	1.5	870,263.81
West Virginia	1,356,793				476,603.05	238,301.50	25.4	113,032.96	56,516.49	6.8	1,061,975.01
Wisconsin	3,045,557	136,427.90	68,213.94	.2	1,108,393.34	542,166.38	56.7	625,709.00	292,619.54	28.0	2,142,537.14
Wyoming	1,559,444	428,050.79	263,631.00	79.5	1,942,219.94	1,196,192.00	177.2	142,529.48	60,636.00	17.9	38,985.00
District of Columbia											
Hawaii	609,375							71,970.96	35,985.48	.5	573,389.52
TOTALS	121,875,000	3,776,818.64	2,025,159.37	552.6	53,074,107.57	27,997,989.69	2,675.9	40,334,343.71	20,450,616.01	1,456.0	71,401,234.93

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF NOVEMBER 30, 1935

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Fund	Miles	Estimated Total Cost	Works Program Fund	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 281,438	$ 281,438	12.5	$ 2,611,603	$ 2,611,603	70.7	$ 1,258,075
Arizona	2,569,841				384,629	384,628	42.3	879,360	850,559	33.5	1,334,653
Arkansas	3,352,061				305,463	304,587	21.8	1,348,333	1,347,355	104.2	1,700,119
California	7,747,928							3,346,973	3,140,802	128.3	4,607,126
Colorado	3,395,263				185,953	185,953	10.1	605,614	605,614	34.2	2,603,696
Connecticut	1,418,709										1,418,709
Delaware	900,310							442,106	442,106	41.6	458,204
Florida	2,597,144				189,094	189,094	.9	565,447	565,447	19.6	1,842,602
Georgia	4,938,967							353,407	353,407	20.3	4,635,561
Idaho	2,222,747				181,561	180,561	16.5	290,539	275,334	27.1	1,766,552
Illinois	8,694,009				929,118	929,118	34.4	2,401,403	2,401,403	126.8	5,363,487
Indiana	4,941,255				214,413	214,413	3.0	2,448,713	2,448,713	136.4	2,278,129
Iowa	4,931,664				416,188	395,200	16.5	545,634	514,516	127.3	4,080,948
Kansas	4,994,975				276,219	276,219	7.5	1,863,110	1,862,110	229.6	2,856,646
Kentucky	3,726,271				228,593	202,349	27.9	1,722,954	1,669,050	238.2	1,854,873
Louisiana	2,890,429							1,332,857	1,026,991	150.3	1,863,438
Maine	1,676,799				332,279	332,279	17.3	708,898	708,898	29.3	635,622
Maryland	1,750,738							155,922	155,922	6.8	1,594,816
Massachusetts	3,262,885										3,262,885
Michigan	6,301,414	$ 352,450	$ 352,450	10.5	3,118,850	3,118,850	153.0	2,832,621	2,779,611	110.4	50,503
Minnesota	5,277,145				519,842	452,411	61.6	281,940	281,940	67.7	4,542,795
Mississippi	3,457,552				291,000	291,000	12.6	1,353,059	1,353,059	90.6	1,813,493
Missouri	6,012,652				586,632	586,632	135.5	2,417,637	2,417,637	522.8	3,008,383
Montana	3,676,416				292,904	292,904	17.4	1,321,542	1,321,542	88.9	2,061,970
Nebraska	3,870,739				339,342	339,342	27.9	1,223,132	1,223,132	127.0	2,308,265
Nevada	2,243,074				457,187	457,187	10.7	316,121	304,121	15.9	1,481,766
New Hampshire	945,225				196,152	194,182	5.5	7,454	7,454	.8	743,589
New Jersey	3,129,805				448,969	448,969	6.7	65,720	65,720	1.8	2,615,116
New Mexico	2,871,397				217,378	215,379	25.9	425,377	425,377	29.2	2,230,641
New York	11,046,377				1,983,638	1,960,887	16.6	3,041,270	3,026,270	25.5	6,059,220
North Carolina	4,720,173				523,847	523,847	42.0	463,470	463,470	26.2	3,732,856
North Dakota	2,867,245	70,277	70,277	9.2	252,537	252,537	45.0	154,005	154,005	17.2	2,390,427
Ohio	7,670,815				239,650	239,650	3.7	1,878,702	1,878,702	18.2	5,552,463
Oklahoma	4,580,670							1,010,842	1,010,792	107.6	3,569,878
Oregon	3,038,642				654,091	654,091	9.5	892,035	882,035	53.4	1,502,516
Pennsylvania	9,347,797							277,633	277,633	10.2	9,070,164
Rhode Island	989,208				38,695	38,695		61,555	61,555	3.6	888,958
South Carolina	2,702,012				262,376	262,376	23.0	179,465	179,465	19.6	2,260,171
South Dakota	2,976,454	7,484	7,484	5.3	299,666	299,666	108.0	436,452	436,452	106.6	2,232,851
Tennessee	4,192,460				292,862	292,862	14.5	279,476	279,476	15.7	3,620,121
Texas	11,989,350				1,006,509	975,953	79.0	4,256,438	4,146,944	401.4	6,866,454
Utah	2,067,154				197,613	194,268	10.6	295,098	270,970	35.1	1,601,915
Vermont	924,306				105,023	105,023	3.3	136,699	136,699	5.3	682,584
Virginia	3,652,667				446,711	446,711	378.5	668,782	668,782	143.9	2,537,174
Washington	3,026,161				579,985	579,985	19.5	871,710	820,876	45.4	1,625,300
West Virginia	2,231,412				282,277	282,277	17.7	467,989	457,592	20.3	1,491,542
Wisconsin	4,823,884				505,445	405,517	30.5	1,202,921	927,344	71.6	3,491,024
Wyoming	2,219,155							470,696	470,694	21.2	1,748,461
District of Columbia	949,496				276,255	276,255	2.4	447,761	439,425	3.7	233,816
Hawaii	926,033										926,033
TOTALS	195,000,000	430,211	430,211	25.0	18,340,404	18,064,595	1,471.3	49,360,475	48,148,604	3,731.0	126,356,590

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF NOVEMBER 30, 1935

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		
				Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected by Signals or Otherwise	
Alabama	$ 4,034,617					$ 596,130	$ 596,130	8		$ 1,977,742	$ 1,977,739	21		$ 1,460,748
Arizona	1,256,099					50,000	50,000	1						1,206,099
Arkansas	3,574,060					100,870	100,870	3		450,467	448,842	9		3,024,349
California	7,486,362					30,070	29,175			3,744,934	3,588,557	23		3,868,630
Colorado	2,631,567					236,145	236,145	7		114,450	114,450	2		2,280,971
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					209,959	209,959	2		750,174	750,174	7		1,867,751
Georgia	4,895,949													4,895,949
Idaho	1,674,479					55,820	55,820	1		381,869	359,693	6		1,258,967
Illinois	10,307,184									1,187,449	1,187,449	16		9,119,735
Indiana	5,111,096					517,576	517,576	3		1,850,742	1,850,742	9		2,742,778
Iowa	5,600,679					579,844	552,700	9		325,954	310,800	8		4,737,179
Kansas	5,246,258									128,206	128,206	1		5,118,052
Kentucky	3,672,387									877,704	849,890	12		2,822,497
Louisiana	3,213,467													3,213,467
Maine	1,426,861					79,488	79,013	1		96,030	96,030	2		1,251,818
Maryland	2,061,751									505,309	505,309	4		1,556,442
Massachusetts	4,210,833									756,997	756,997	3		3,453,836
Michigan	6,765,197					1,447,575	1,447,575	16		1,992,277	1,992,277	20		3,325,345
Minnesota	5,395,441									380,086	380,086	14		5,015,355
Mississippi	3,241,475									795,730	795,730	16		2,445,745
Missouri	6,142,153									398,429	398,429	4		5,743,724
Montana	2,722,327					193,192	193,192	2		990,647	990,647	18		1,538,488
Nebraska	3,556,441					47,152	47,152	1		923,029	923,029	29		2,586,260
Nevada	887,260					322,457	322,457	7		56,287	56,287	1		508,515
New Hampshire	822,484													822,484
New Jersey	3,983,826													3,983,826
New Mexico	1,725,286									157,986	144,159	2		1,581,127
New York	13,577,189					512,966	507,510	3		2,751,960	2,653,460	4		10,416,219
North Carolina	4,823,958					258,286	258,286	1		525,181	525,181	7		4,040,491
North Dakota	3,207,473					39,335	39,335	2						3,168,138
Ohio	8,439,897									126,598	126,598			8,313,299
Oklahoma	5,004,711					139,826	139,826	2		739,959	739,959	14		4,124,926
Oregon	2,334,204									697,553	695,792	5		1,638,412
Pennsylvania	11,483,613					10,500	10,500			296,734	258,591	5		11,214,522
Rhode Island	699,691					275,115	275,115	3						424,576
South Carolina	3,059,956					95,982	95,982	2		429,675	429,675	10		2,534,298
South Dakota	3,249,086					48,782	48,782	2		51,774	51,774	1		3,148,530
Tennessee	3,903,979									287,070	287,070	5		3,616,909
Texas	10,855,982					66,713	66,713	3		387,341	387,341	9		10,401,928
Utah	1,230,763									158,359	158,359	1		1,072,404
Vermont	729,857					98,394	98,394			191,142	188,495	3		442,968
Virginia	3,774,287									209,501	209,501	6		3,564,786
Washington	3,095,041					112,262	112,262	2		952,828	950,931	8		2,031,848
West Virginia	2,677,937													2,677,937
Wisconsin	5,022,683					345,870	345,870	5		595,703	497,607	5		4,179,206
Wyoming	1,360,841					55,365	55,365	2						1,305,476
District of Columbia	410,804									166,697	166,697	2		244,107
Hawaii	453,703													453,703
TOTALS	196,000,000					6,525,674	6,491,704	88		27,410,573	26,932,553	312		162,575,743

PUBLICATIONS *of the* BUREAU OF PUBLIC ROADS

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Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933.

Report of the Chief of the Bureau of Public Roads, 1934.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T . . . Electrical Equipment on Movable Bridges. 5 cents.

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No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

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No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

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The Taxation of Motor Vehicles in 1932. 35 cents.

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Reports on Subgrade Soil Studies. 40 cents.

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SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF NOVEMBER 30, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Fund	1935 Public Works Fund	Mileage	1934 Public Works Fund	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,269,842	$ [illegible]	$ 7,093,668	775,239	666.2	$ 2,272,818	$ 546,486	$ 1,520,372	33.1	$ 11,886	$ 395,076	13.2	$ 69,093	$ 571,154
Arizona	5,211,960	2,641,335	8,024,[illegible]	[illegible]	[illegible]	522.9	754,891	133,822	507,747	22.7		72,390	.5	16,484	79,183
Arkansas	6,748,335	3,428,049	8,802,708	[illegible]	[illegible]	474.6	1,890,977	274,635	1,604,476	124.4	149,928	73,548	6.5	64,953	169,606
California	15,607,354	7,932,206	25,052,065	15,123,463	[illegible]	[illegible]	5,108,431	478,067	2,776,765	44.8		134,947	.7	[illegible],824	170,511
Colorado	6,874,530	3,456,006	11,045,871	6,810,235	[illegible]	[illegible]	104,162	9,323	94,839	6.0				54,972	18,222
Connecticut	2,865,740	1,454,568	4,216,908	2,353,541	942,378	[illegible]	359,166		343,645	3.7		58,859	.1	6,199	109,986
Delaware	1,814,066	923,795	2,043,119	1,818,961	770,496	124.3	43,114		43,114					126	[illegible]
Florida	5,251,854	2,661,345	7,831,039	5,139,970	[illegible]	265.8	997,002	29,832	876,389	41.5		178,955	1.7	62,032	[illegible],760
Georgia	10,091,185	5,113,491	11,294,299	8,909,817	1,380,930	642.7	1,652,417	696,214	908,178	82.1	87,819	552,748	24.8	397,33[illegible]	1,671,039
Idaho	4,486,249	2,277,486	6,165,523	4,416,876	1,385,796	473.4	644,401		644,152	18.0		56,567	2.8	69,413	151,772
Illinois	17,570,770	8,921,401	18,507,797	14,691,843	3,723,471	525.5	7,473,890	2,769,522	4,664,368	154.1		363,062	6.0	109,345	470,500
Indiana	10,037,843	5,088,963	10,858,684	9,077,334	1,545,364	318.3	4,227,962	791,449	3,401,671	168.2	51,719	80,140	2.2	117,230	262,389
Iowa	10,055,660	5,118,761	15,062,366	9,883,155	4,404,511	1,196.3	667,507	170,404	457,100	28.9		1,000	2.7	2,101	[illegible]
Kansas	10,084,604	5,117,675	13,693,565	9,990,654	3,338,905	1,059.3	1,814,435	34,153	1,752,734	80.2	48,918	21,[illegible]	2.2	8,878	4,810
Kentucky	7,517,[illegible]	3,818,311	9,768,148	6,906,083	2,307,931	722.1	1,865,608	508,224	1,163,173	82.9	55,381	134,047	14.7	47,671	21[illegible],102
Louisiana	5,826,591	2,963,932	6,363,361	4,555,079	1,239,327	192.6	2,402,139	1,058,401	1,301,765	52.9	155,417	376,243	17.1	[illegible]	45,927
Maine	3,369,917	1,711,[illegible]	4,908,431	3,347,218	1,366,107	184.0	299,803		299,788	9.0				22,699	45,691
Maryland	3,564,527	1,810,058	3,337,991	2,654,437	600,931	113.2	1,911,608	814,974	270,944	29.5		347,376	5.6	95,116	590,807
Massachusetts	6,597,100	3,350,474	6,663,406	4,589,803	1,490,629	100.1	3,533,896	1,974,333	1,559,563	15.2				32,964	300,283
Michigan	12,736,227	6,452,568	17,067,079	12,486,352	3,679,826	637.8	2,939,652	181,827	2,697,425	131.0		44,725	.1	68,048	30,592
Minnesota	10,656,569	5,425,551	15,213,536	9,915,264	4,649,353	1,614.5	1,026,898	625,234	326,027	34.5	4,974	193,990	1.8	111,098	256,180
Mississippi	6,978,675	3,540,227	9,426,502	5,637,571	1,255,577	542.4	3,275,715	1,202,529	1,711,276	175.5	7,240	424,827	23.1	131,335	150,547
Missouri	12,180,306	6,173,740	14,009,606	10,650,272	2,516,802	1,280.9	4,934,807	1,401,152	3,325,773	169.9		270,597	.6	128,882	60,567
Montana	7,439,748	3,769,734	11,001,836	7,142,543	3,224,257	996.7	601,107	155,193	445,914	27.0	47,265		7.2	94,746	99,563
Nebraska	7,828,961	3,964,364	11,334,475	7,752,426	2,389,671	966.1	1,791,666	34,041	1,466,441	67.8		2,890	.1	42,495	105,362
Nevada	4,545,917	2,302,356	6,640,601	4,502,450	1,985,406	735.6	359,003	26,150	296,747	21.7		1,650		17,317	18,553
New Hampshire	1,909,839	969,462	2,708,347	1,736,886	869,856	73.4	64,751		64,751	.4	172,557	11,610	4.0	396	23,245
New Jersey	6,346,039	3,220,879	6,945,166	6,014,766	573,497	75.6	2,620,445	175,941	2,187,571	12.5				155,332	459,811
New Mexico	5,792,935	2,941,700	8,132,696	5,597,600	2,356,078	749.0	476,368	37,087	439,281	19.7				158,247	146,342
New York	22,330,101	11,327,921	33,493,920	21,273,118	6,845,227	710.0	6,391,294	881,051	3,798,672	112.9	12,000	197,250	.4	163,933	486,772
North Carolina	9,522,293	4,840,941	13,460,464	8,782,872	3,443,982	1,273.3	1,436,786	361,426	1,058,466	72.5	64,450	256,483	4.6	313,545	82,010
North Dakota	5,804,448	2,936,967	7,330,724	5,535,549	1,160,838	1,937.0	727,277	130,778	530,181	115.9	73,549	535,989	70.2	64,573	711,958
Ohio	15,484,592	7,365,012	21,449,131	15,279,029	4,598,579	729.4	3,016,201	161,431	2,617,675	46.2		464,072	13.3	44,132	184,686
Oklahoma	9,216,798	4,685,180	12,570,003	8,874,286	2,866,902	747.7	1,640,267	323,398	1,295,626	55.3		157,418	1.2	19,114	343,235
Oregon	6,106,390	3,047,814	9,390,442	5,905,905	2,676,970	461.4	434,974	99,039	264,264	4.0	518			101,434	156,580
Pennsylvania	18,891,004	9,590,788	26,935,166	17,838,787	7,914,430	983.0	1,909,182	824,982	997,947	97.9	5,126	313,372	2.1	222,109	365,038
Rhode Island	1,998,708	1,014,572	2,683,878	1,944,409	645,099	78.0	342,956		342,956	8.2	50,004	6,400	3.0	4,295	20,117
South Carolina	5,459,165	2,770,954	5,798,581	4,956,743	733,453	444.7	1,997,871	375,718	1,581,760	174.5	15,740	52,612	.2	110,964	403,130
South Dakota	6,011,479	3,047,645	8,440,333	5,735,919	2,155,866	1,453.1	493,947	63,435	430,512	67.8	6,425	377,865	30.2	205,699	83,401
Tennessee	8,492,619	4,302,991	11,418,657	8,109,360	2,411,687	440.2	1,674,652	242,654	1,335,596	41.3	14,917	218,803	3.1	125,688	336,905
Texas	24,244,024	12,291,253	31,647,062	23,390,457	6,777,509	2,554.8	5,808,806	554,065	5,032,249	216.3	265,315	361,123	20.9	34,186	120,372
Utah	4,194,708	2,132,691	6,508,661	4,000,360	1,743,966	574.5	670,555	167,060	352,191	16.5		1,000		27,288	35,534
Vermont	1,867,573	948,007	3,008,839	1,831,050	848,613	137.2	109,059	3,922	90,873	2.4		2,713		32,601	5,808
Virginia	7,416,757	3,765,387	10,871,897	7,102,575	2,893,222	553.2	885,456	195,954	648,068	64.3	42,221	44,360	.7	76,007	179,736
Washington	6,115,867	3,106,412	8,360,578	5,902,257	2,243,798	291.1	1,002,931	198,743	793,090	11.7		8,673		14,867	55,851
West Virginia	4,474,234	2,280,335	5,186,232	4,169,050	861,104	182.6	1,262,572	269,126	960,378	35.8	8,585	51,810	.1	27,474	407,044
Wisconsin	9,724,881	4,941,837	14,546,899	9,653,297	4,075,468	604.2	810,676	7,300	749,370	15.1		97,922	1.2	64,284	19,077
Wyoming	4,501,327	2,287,712	6,482,834	4,446,531	1,850,903	977.1	453,856	46,705	380,415	60.2		56,394		8,091	
District of Columbia	1,918,469	973,342	2,542,275	1,918,173	624,102	18.8	153,249		153,249	1.4		160,094	2.1	296	30,398
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,417,635	700,733	543,829	19.0	39,709	169,484	2.0		236,464
TOTALS	394,000,000	200,000,000	532,988,922	369,012,098	120,549,562	31,887.3	88,775,841	19,795,563	61,013,976	2,968.0	1,391,663	7,348,367	289.6	3,800,676	11,088,095

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A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 16, NO. 11 JANUARY 1936

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Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 16, No. 11 January 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

DIGEST OF REPORT ON CONNECTICUT TRAFFIC SURVEY

Reported by L. E. PEABODY, Senior Highway Economist, Division of Highway Transport, Bureau of Public Roads

THE Connecticut traffic survey was conducted under a cooperative agreement between the Bureau of Public Roads and the State Highway Department of Connecticut.[1] The survey was begun October 6, 1933, and was completed September 30, 1934.

CONNECTICUT IS DENSELY POPULATED AND HAS HEAVY TRAFFIC ON ITS HIGHWAYS

Connecticut's population increased 16.4 percent between the censuses of 1920 and 1930. The State is one of four in which all counties had population increases during these years. In 1930 its population density was 333.4 persons per square mile, or more than eight times the population density in the United States as a whole.

The number of motor vehicles registered in Connecticut increased steadily until 1932, the first year to show a decline. This was followed by a smaller decrease in 1933, and in 1934 the losses in registration in the 2 previous years were more than made up when nearly 358,000 motor vehicles were registered, the greatest number in the history of the State.

Gasoline consumption in Connecticut has followed an upward trend except for the year 1932 when there was a decrease of 2.2 million gallons, or 1 percent. In 1934 the consumption was almost 249 million gallons, an increase of 239 percent since 1922.

Traffic on Connecticut highways is composed of many foreign vehicles owing to the geographical position of the State. Surrounded by the heavily populated States of New York, Massachusetts, and Rhode Island, it is in a position where traffic arteries must be provided for many vehicles originating at and destined to points beyond its borders, and must provide as well for the free movement of its own vehicles. Near the southwestern extremity of Connecticut is New York City, with a population of approximately 7 million people; to the north is Massachusetts with a population in excess of 4 million, of which nearly 1 million are concentrated in the Boston area; and to the east is Rhode Island, with a population of approximately 700,000.

There are 11,943 miles of highway in Connecticut, exclusive of city streets. The State highway system covers a total of 2,206 miles, of which 1,019 miles are also on the Federal-aid system. All trunk-line and State-aid roads, which compose the State highway system, are under the direct jurisdiction of the State highway department; for the former the State pays the entire cost of construction, while for the latter the State pays a part of the construction cost. All other rural roads are under the jurisdiction of the towns.

SELECTION AND OPERATION OF SURVEY STATIONS DESCRIBED

The traffic survey covered a major portion of the trunk-line system and a number of State-aid roads. Survey stations were situated only on State or United States routes, but, where intersecting town roads or city streets could be covered along with the principal route, traffic data for such were included in the final tabulations.

Recording stations were located at 156 strategic traffic control points throughout the State where traffic density counts were obtained on the average more than once a month. The locations of these stations are shown in figure 1. The positions of all survey stations were selected in advance of field operations by the State highway department in cooperation with a representative of the Bureau of Public Roads. Each station location was assigned a number by which it may be identified in this report.

Vehicles were recorded at all stations as either Connecticut or foreign and as passenger cars, trucks, and busses. Traffic counts were made at each station for a continuous 8-hour period on a staggered-hour plan alternating from 6 a. m. to 2 p. m. and from 2 p. m. to 10 p. m. in accordance with a schedule covering a full year's work. Sufficient counts were made from 10 p. m. to 6 a. m. to adjust all records to a 24-hour day, and the data are presented on a 24-hour basis.

The data obtained are presented in the flow diagrams, figures 2, 3, 4, and 5. Figure 2 shows the average daily density of all vehicular traffic by the inner stippled band and the average maximum traffic over the same section by the outer band. At intermediate points between or beyond stations approximate density data for each class of traffic may be obtained by scaling the particular band and converting to the number of vehicles by scale on the figure. For routes having light traffic densities it was impracticable to construct flow bands, therefore, their values are represented by line symbols.

Figure 3 illustrates the average density of truck traffic on the same sections of highway; figure 4 shows the average density of bus traffic; and figure 5 shows the average density of foreign vehicular traffic. For simplicity only major cities and intersections are shown, and where a route has both a State and a United States number only the United States marking is given. Table 1 shows the distribution of the traffic between foreign and State vehicles and according to classes of vehicles.

TABLE 1.—*Classification of traffic by type of vehicle and place of registration*

	Passenger cars	Trucks	Busses[1]	Total
	Percent	*Percent*	*Percent*	*Percent*
Connecticut vehicles	84.3	13.9	1.8	100
Foreign vehicles	89.7	10.2	.1	100
All vehicles	85.5	13.1	1.4	100
Connecticut vehicles	76.3	82.3	99.4	77.4
Foreign vehicles	23.7	17.7	.6	22.6
Total	100.0	100.0	100.0	100.0

[1] All busses making regular trips in State were required to carry Connecticut tag and were recorded as Connecticut vehicles.

An overwhelming proportion of bus traffic was of Connecticut registration (99.4 percent). This results

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[1] The full report prepared by the Bureau has been submitted to the Connecticut highway department and will not be published or distributed by the Bureau of Public Roads.

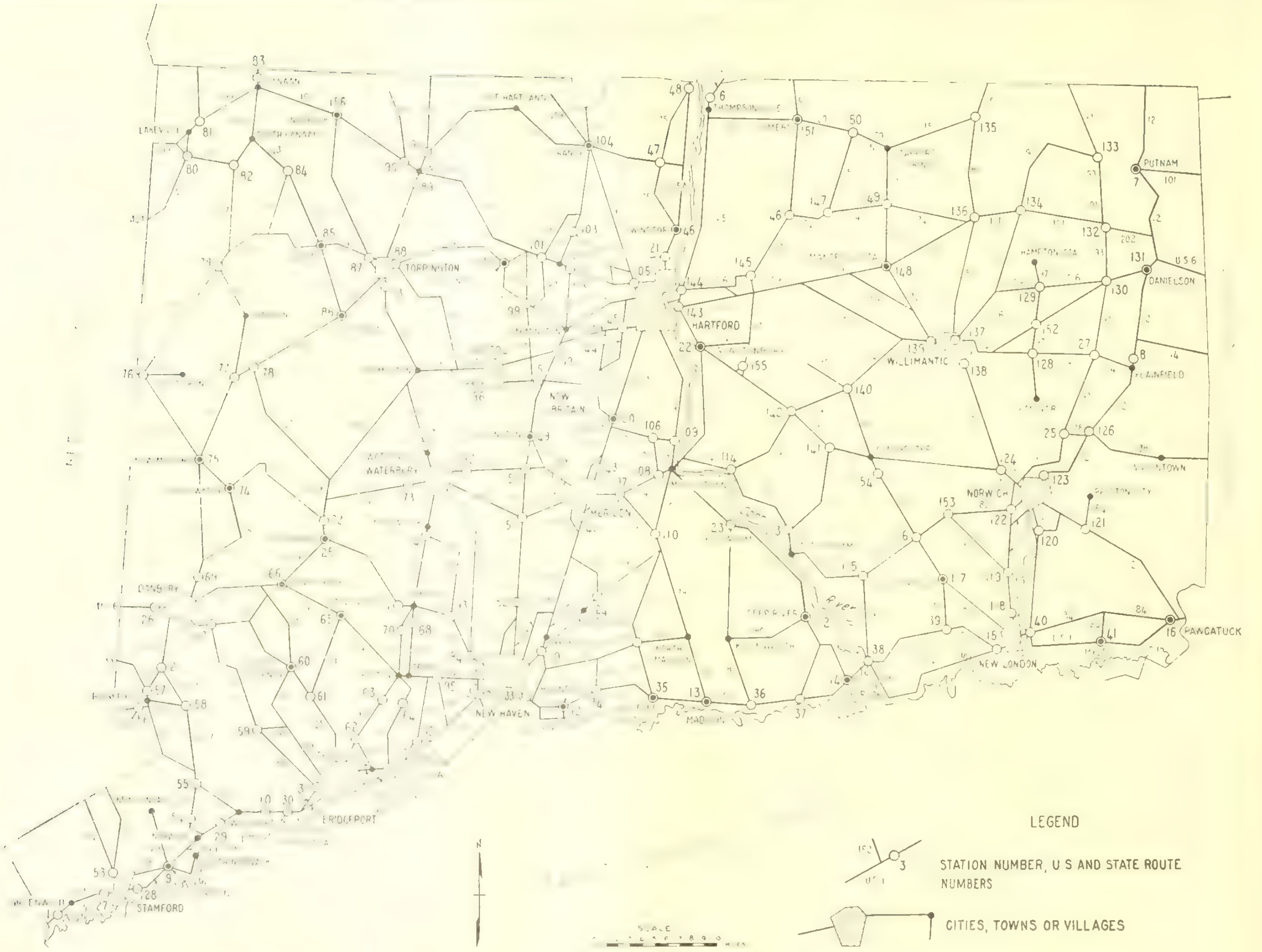

Figure 1.—Locations of Traffic Recording Stations.

from a legislative act that requires all busses making regular trips through the State to carry Connecticut registration tags. The few busses observed without Connecticut tags were principally chartered busses for special events such as football games, seashore outings, etc.

U S 1 CARRIES HEAVIEST TRAFFIC

As shown in figure 2, traffic was heavily concentrated on the trunk-line highways, especially on routes such as U S 1 from east to west, and U S 5 and U S 5A from north to south. The section of U S 1 between New Haven and the New York State line, a portion of the old Boston Post Road, carries traffic from a number of routes converging at New Haven and serves the important cities of Bridgeport, Norwalk, and Stamford.

Figure 6 shows the principal through routes in the State classified according to the average daily density of all local vehicular traffic on each section. These values are based on counts made at survey stations situated along the routes and are grouped in convenient categories. Symbols used for each class are shown in the figure.

Table 2 contains data on the average daily traffic on principal highways throughout the State.

Traffic on through routes traversing heavily populated areas exhibited interesting characteristics, especially with regard to the influence of local and through travel and the use of bypass highways. Figure 7 shows traffic densities as ordinates and the locations along U S 1 of large cities and intersections as abscissas. The black area represents traffic flow on U S 1 and the stippled area represents traffic on the bypass road U S 1A.

The greatest volume of traffic recorded on this route occurred on the section immediately west from New Haven to the intersection with State route 158. This section had a daily average flow of 20,929 vehicles throughout the year. Not only was traffic on this section the heaviest for U S 1 but also for all roads throughout the State.

In figure 7 three general features of traffic flow along the route are evident: (1) Traffic west of New Haven is considerably in excess of that east of the city; (2) bypass roads in the vicinity of Bridgeport functioned for the purpose intended, and the sum of the traffic volumes on the bypass and the old road approximated the average route flow; and (3) traffic densities increased near large cities because of local traffic.

AVERAGE DAILY TRAFFIC COMPARED WITH AVERAGE MAXIMUM TRAFFIC

The maximum traffic densities are developed from data obtained on the particular dates of operation of each station and are a measure of the average maximum traffic. The term "average maximum traffic" has specific reference to the normal peak load existing during the summer periods of heavy week-end travel and

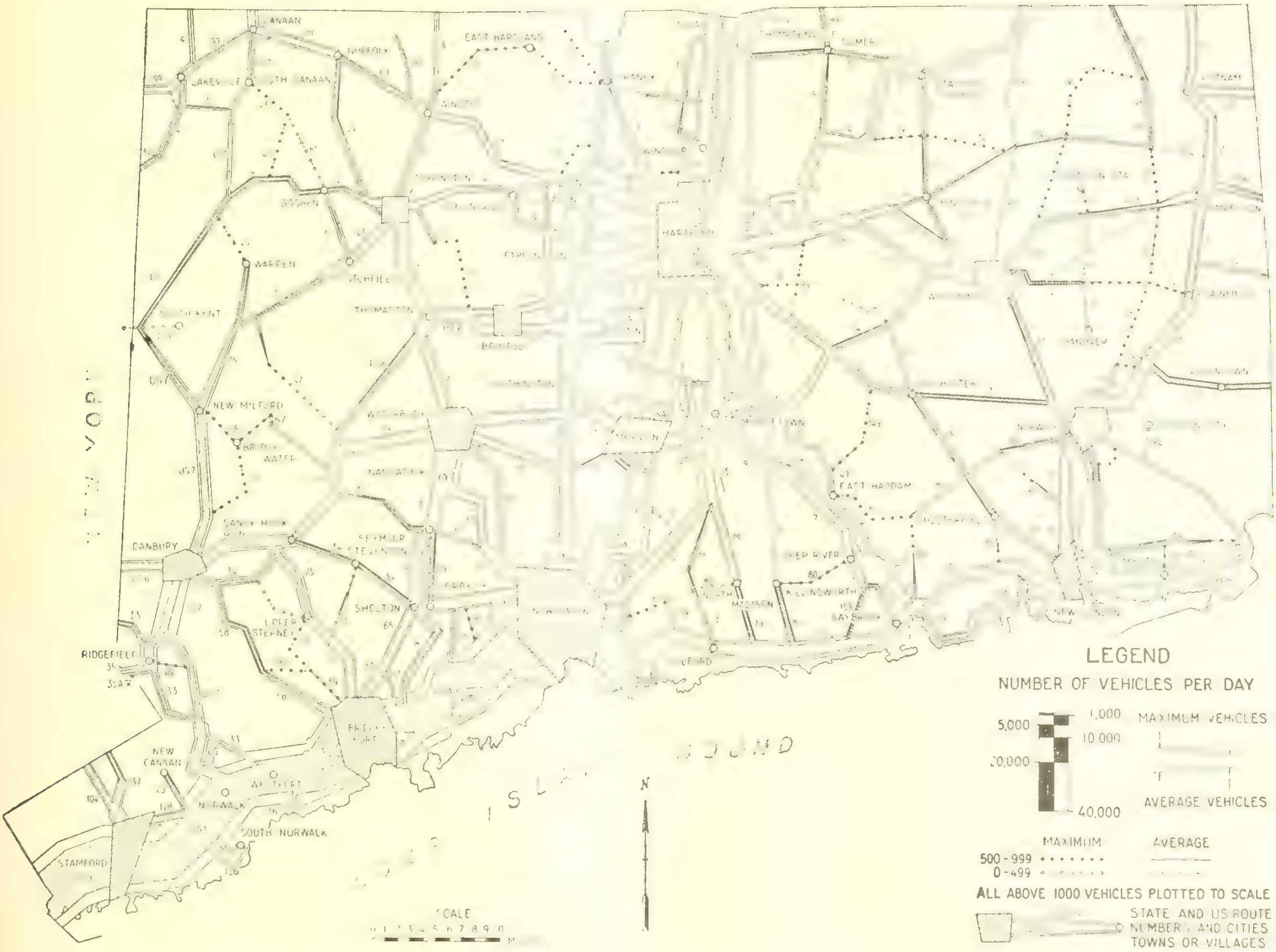

FIGURE 2.—TRAFFIC FLOW BANDS FOR AVERAGE DAILY AND AVERAGE MAXIMUM MOTOR-VEHICLE TRAFFIC. CITY BOUNDARIES ARE DISTORTED TO ALLOW FOR WIDTHS OF TRAFFIC FLOW BANDS.

TABLE 2.—*Average daily traffic on selected highways*

Description of highway		Average daily traffic, all vehicles				Average daily traffic, foreign vehicles	Average daily traffic, local vehicles
Route	Termini and principal points along section	Passenger cars	Trucks	Buses	Total		
U S 1	New York State line, New Haven	12,735	1,903	265	14,903	5,609	9,294
U S 5	New Haven, Meriden, Hartford, Massachusetts State line	5,921	947	154	7,022	1,841	5,181
Conn. 9	Hartford, Middletown	5,238	691	85	6,014	381	5,633
U S 5A	Hartford, Windsor, Massachusetts State line	4,920	890	138	5,948	1,806	4,142
U S 1	New Haven, New London, Rhode Island State line	4,193	663	74	4,930	1,433	3,497
Conn. 65 and 8	Bridgeport, Waterbury, Torrington	3,306	656	40	4,002	368	3,634
Conn. 32	New London, Norwich	3,324	499	55	3,878	370	3,508
Conn. 10	New Haven, Farmington	3,300	468	23	3,791	488	3,303
Conn. 12	Norwich, Putnam, Massachusetts State line	2,774	526	52	3,352	605	2,747
Conn. 15	New Haven, Middletown, Junction Conn. 2 and Conn. 15	2,680	403	47	3,130	828	2,302
Conn. 83, 74, and 15	South Manchester, Rockville, Stafford Springs, Massachusetts State line near Mashapaug.	2,590	319	92	3,001	1,098	1,903
U S 6	New York State line, Danbury, Hartford	2,527	274	18	2,819	809	2,010
Conn. 9	Middletown, Saybrook	2,136	304	23	2,463	152	2,311
Conn. 199 and 101	New York State line, Canaan, Winsted, Hartford	2,074	276	23	2,373	503	1,870
U S 6	Hartford, Willimantic, Danielson, Rhode Island State line	1,739	303	41	2,083	629	1,454
Conn. 2	Junction Conn. 2 and Conn. 15, Colchester, Norwich, Rhode Island State line	1,527	237	17	1,781	251	1,530
Conn. 12	New London, Norwich	1,462	254	31	1,747	189	1,558
Conn. 2 and 15	Hartford, Junction Conn. 2 and Conn. 15 (connecting link for routes Conn. 2 and Conn. 15 to Hartford).	4,837	721	106	5,664	709	4,955

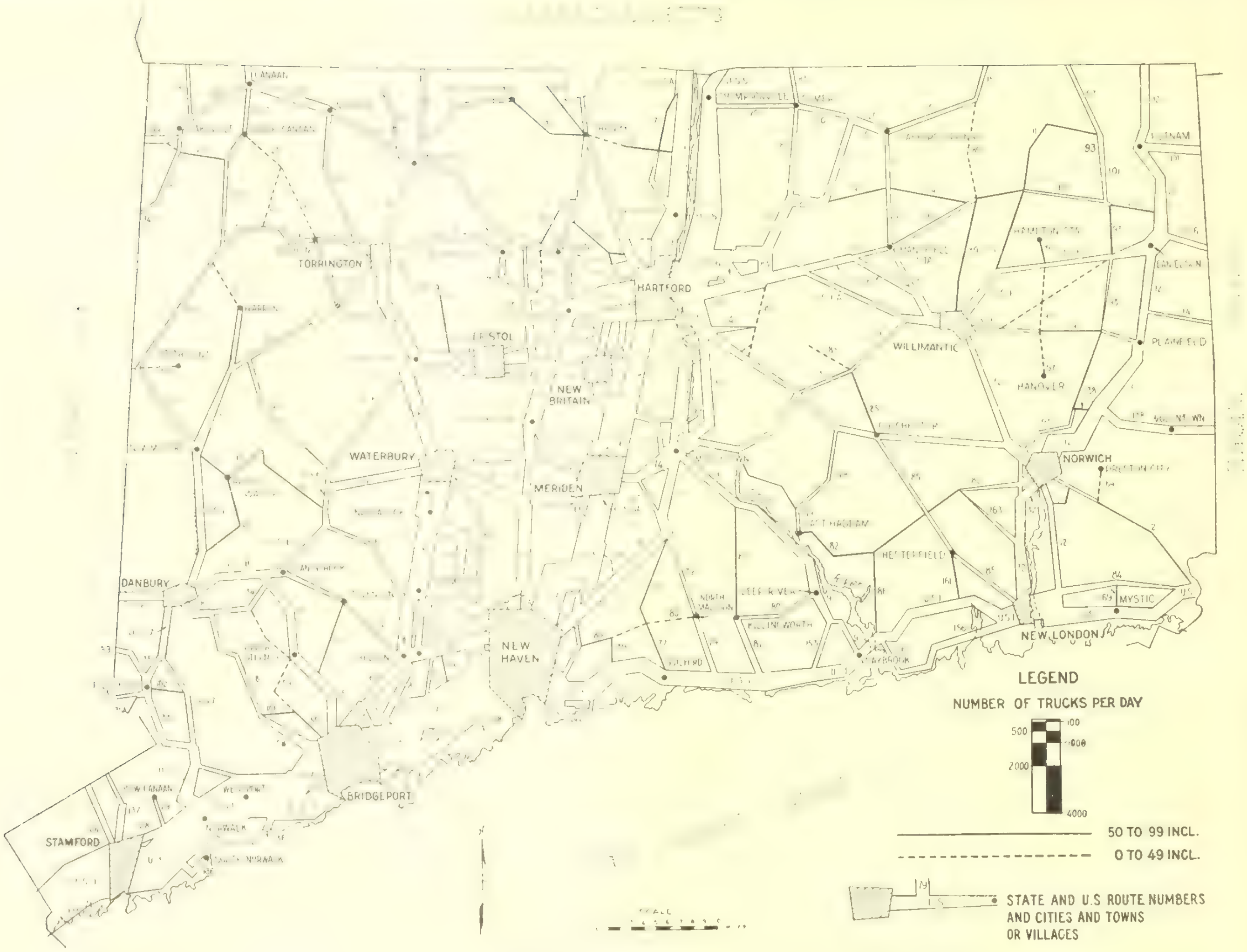

FIGURE 3.—TRAFFIC FLOW BANDS FOR AVERAGE DAILY TRUCK TRAFFIC.

should not be confused with the precise peak or actual maximum count of the year. Sunday or Monday of the Labor Day period, and Independence Day when occurring on a Saturday or Monday, are known to have maximum peaks of traffic for most highways; however, a county fair or local celebration might produce the maximum. The average maximum traffic throughout the State occurred on a Sunday in August.

At traffic survey station 2, located at the junction of U S 7 and Connecticut 35, the peak volume occurred on Sunday, October 8, during the progress of the Danbury County Fair. On this day there was recorded on U S 7, north from the station toward Danbury, a total of 7,180 vehicles from 2 p. m. to 10 p. m., when normally a traffic density not to exceed 1,800 vehicles would be the expected volume for this period and season.

The highway engineer is concerned with the average maximum traffic on any section of highway for which he must make improvements within the limits of available funds.

It is not economical to design surface widths and intersections for a free flow of traffic during those extreme peaks that occur once or twice a year. At such times some sacrifice must be made in freedom of flow to accommodate the increased volume.

For those highways covered by the survey, as a group, the average maximum traffic was 162 percent of the average daily traffic. At one location, on Connecticut 61, a minor route of very low traffic density, a maximum variation of 500 percent was recorded. In general, the ratio of average maximum traffic to average daily traffic varied inversely with the volume of the average daily traffic. Highways of relatively low traffic volume had a high ratio of average maximum to average daily traffic, and, conversely highways with heavy traffic volumes generally did not exhibit a high ratio. In Connecticut, 50 sections of highways had a ratio in excess of 200 percent.

Along U S 1 from the New York State line to New Haven, the average maximum traffic was 23,361 vehicles per day and the average daily traffic was 14,903 vehicles. The net difference in the two values represents an increase of approximately 8,500 vehicles per day, although the ratio of increase is but 57 percent. Similarly, on U S 5 north from New Haven via Hartford to the Massachusetts State line near Thompsonville, the average maximum traffic density for the route averaged 10,619 vehicles per day. Comparing this with the average daily traffic density of 7,022 vehicles for this route, the net increase was 3,597 vehicles, or 51 percent. Although the ratios of increase were relatively low, the increments were large.

It is interesting to compare the results obtained in this survey with results of the 1923 traffic survey in Connecticut made by the Bureau in cooperation with the State highway department. At that time route

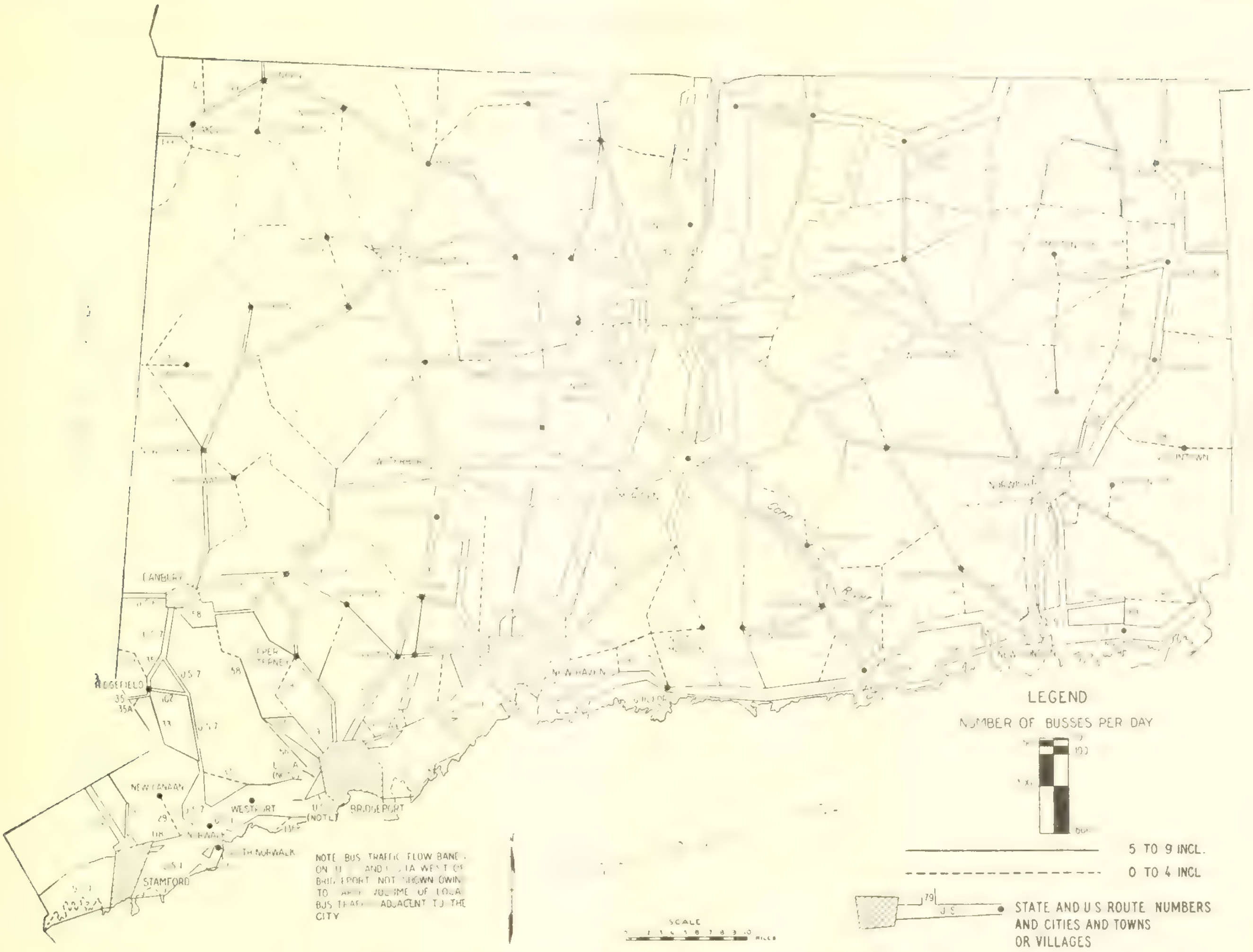
DANBURY
RIDGEFIELD
35
35A
102
33
U S 7
58
NEW CANAAN
29
WESTPORT
NORWALK
SOUTH NORWALK
STAMFORD
U S 1
(NOTE)
BRIDGEPORT
NEW HAVEN
NEW LONDON
NOTE: BUS TRAFFIC FLOW BANDS ON U S 1 AND U S 1A WEST OF BRIDGEPORT NOT SHOWN OWING TO LARGE VOLUME OF LOCAL BUS TRAFFIC ADJACENT TO THE CITY
SCALE
MILES
LEGEND
NUMBER OF BUSSES PER DAY
100
5 TO 9 INCL.
0 TO 4 INCL.
STATE AND U S ROUTE NUMBERS AND CITIES AND TOWNS OR VILLAGES
79
U S

Figure 4. Traffic Flow Bands for Average Daily Bus Traffic.

U S 1 between the New York State line and New Haven carried an average maximum traffic of 8,000 vehicles per day, while 11 years later the same highway was subjected to an average maximum traffic of 23,361 vehicles, an increase of 192 percent. On U S 5 the 1923 average maximum traffic was approximately 5,000 vehicles per day, while in 1934 the average maximum traffic was 10,619 vehicles, an increase of 112 percent. These are cases of unusual traffic growth upon appreciable lengths of highways that originally carried heavy traffic and now carry still greater volumes; the traffic volume more than doubled in a decade.

Foreign vehicles constituted approximately 33 percent of the total traffic on Connecticut highways, and it is interesting to observe their effect on the average maximum traffic. Table 3 shows the average daily and average maximum traffic density values for all vehicles and for foreign vehicles on U S 1, U S 5, and U S 5A between the points indicated. By taking the difference between average maximum traffic and average daily traffic and separating this difference into local and foreign classes, foreign vehicles are found to make up 49.3 percent of the increase. In other words, one-third of the vehicles, by registration, were responsible for one-half of the peak load traffic increase. On these selected routes the ratio of average maximum to average daily traffic for Connecticut vehicles amounted to 146 percent and for foreign vehicles 189 percent.

SEASONAL VARIATIONS OF TRAFFIC FOUND TO BE LARGE

A well-established characteristic of motor-vehicle traffic is that the flow is not regular. Variations are due to a number of causes. The most conspicuous variations are for the season of the year, day of the week, and hour of the day. In the absence of known values for seasonal and daily variations, most Statewide surveys are continued for a full-year period in order that each major influence may be considered in determining the final traffic-density figures. Unusually inclement weather and special events are of short duration and the data are readily adjusted to take them into account.

Although traffic is quite variable, the variations repeat themselves in close order from year to year and under similar conditions, so that the limits of changes may be established to a fair degree of accuracy for an extended period.

Table 4 shows the monthly variations in vehicular traffic throughout Connecticut expressed as percentages of the average monthly traffic. These data are based on the average daily traffic during the month irrespective of the number of days contained in the month. Variations throughout the year are illustrated in figure 8, which shows graphically the fluctuations of local, foreign, and total vehicular traffic.

Traffic volume was greatest in August with 141 percent of that of the average month, and least in February

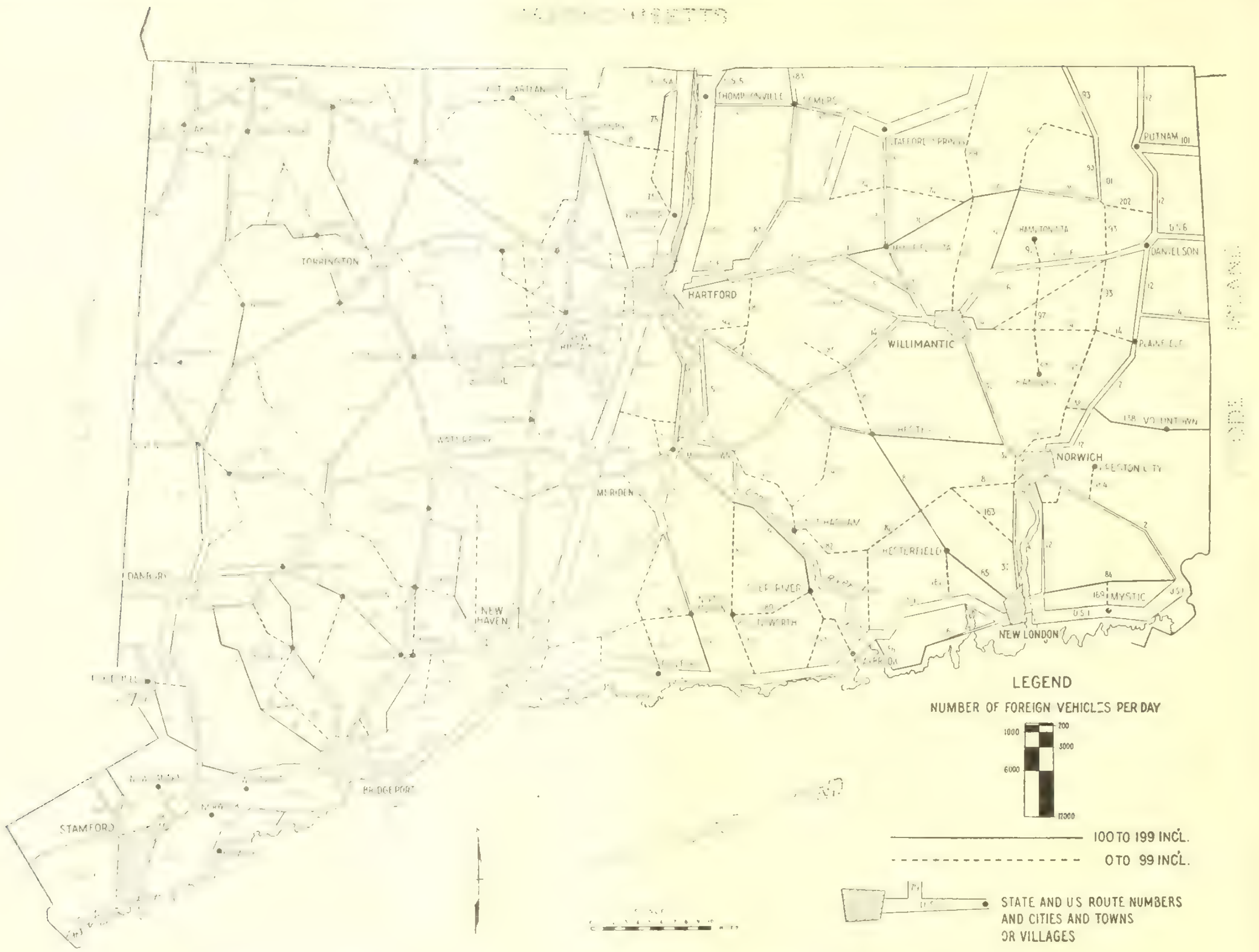

FIGURE 5.—TRAFFIC FLOW BANDS FOR AVERAGE DAILY TRAFFIC OF FOREIGN VEHICLES.

TABLE 3.—*Comparisons of average maximum traffic with average daily traffic on selected routes. Figures are summations of counts at all stations on sections listed*

Stations located between	U S route	Connecticut vehicles			Foreign vehicles			All vehicles		
		Average maximum traffic	Average daily traffic	Increase	Average maximum traffic	Average daily traffic	Increase	Average maximum traffic	Average daily traffic	Increase
New York State line and New Haven	1	206, 949	148, 716	58, 233	166, 834	89, 739	77, 095	373, 783	238, 455	135, 328
New Haven and Rhode Island State line	1	144, 712	94, 427	50, 285	80, 015	38, 681	41, 334	224, 727	133, 108	91, 619
New Haven and Massachusetts State line	5	45, 113	31, 089	14, 024	18, 601	11, 043	7, 558	63, 714	42, 132	21, 582
Hartford and Massachusetts State line	5A	39, 555	24, 856	14, 699	18, 421	10, 834	7, 587	57, 976	35, 690	22, 286
Total		436, 329	299, 088	137, 241	283, 871	150, 297	133, 574	720, 200	449, 385	270, 815
Percentage of total increase				50. 7			49. 3			100. 0

with 49 percent of that of the average month. The approximate periods of average monthly traffic for the State as a whole occurred from the middle of April to the middle of May, and again from the middle of October to the middle of November.

Foreign traffic fluctuated much more widely than did local traffic from a low of 33 percent in February to a high of 172 percent in July. The range for Connecticut vehicles was from 54 percent in February to 134 percent in August. There will be noted an unusual circumstance in that foreign vehicles reached their maximum during the month of July, while Connecticut vehicles were at their maximum during August.

DAILY VARIATIONS IN TRAFFIC FOLLOW WELL-ESTABLISHED TRENDS

Variations in traffic density by the days of the week are shown in table 5 and figure 9, all items being expressed as percentages of the average week-day traffic for each type of vehicle. Week days are from Monday to Friday, inclusive.

The general characteristics of daily variations are well known and change but slightly in different sections of the country. Sunday is the day of greatest travel, with Saturday next. On the remaining five days of the week the traffic is rather uniform. On Sunday the total traffic is 137 percent of the average week-day

Table 4.—*Monthly variations in traffic density expressed as percentages of average monthly traffic*

Month	Passenger cars			Trucks			Busses			All vehicles		
	Connecticut	Foreign	Total	Connecticut	Foreign	Total	Connecticut	Foreign	Total	Connecticut	Foreign	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
January	68	47	[illegible]	87	81	86	99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
February	52	28	[illegible]	[illegible]	68	67	74	[illegible]	71	[illegible]	[illegible]	[illegible]
March	80	63	76	84	100	92	[illegible]	[illegible]	102	82	[illegible]	78
April	97	77	[illegible]	97	82	94	[illegible]	63	[illegible]	[illegible]	78	92
May	117	108	[illegible]	114	132	118	109	[illegible]	[illegible]	[illegible]	[illegible]	115
June	[illegible]	127	124	109	102	108	99	[illegible]	99	[illegible]	125	121
July	120	[illegible]	[illegible]	107	119	109	130	81	130	118	172	132
August	138	[illegible]	146	116	163	113	104	[illegible]	104	134	163	141
September	118	150	126	[illegible]	112	[illegible]	122	[illegible]	121	116	[illegible]	125
October	121	120	[illegible]	118	[illegible]	120	96	[illegible]	97	[illegible]	[illegible]	120
November	94	83	91	105	[illegible]	[illegible]	103	100	103	[illegible]	83	93
December	72	48	66	82	52	[illegible]	87	[illegible]	88	71	48	68

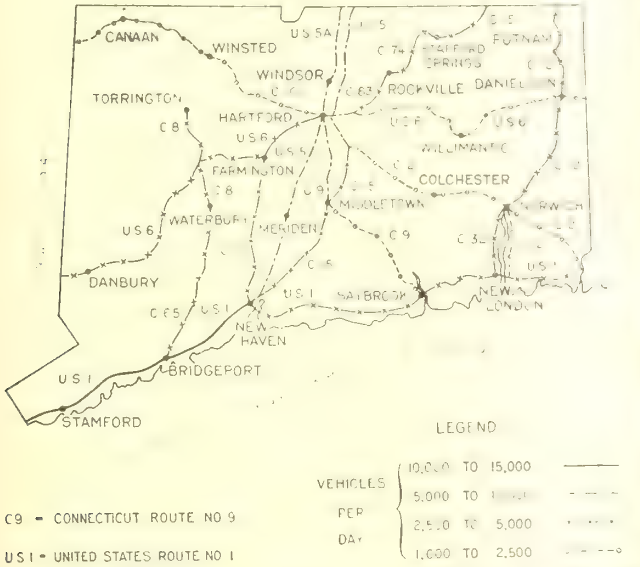

Figure 6.—Principal Highways Classified by Traffic Density.

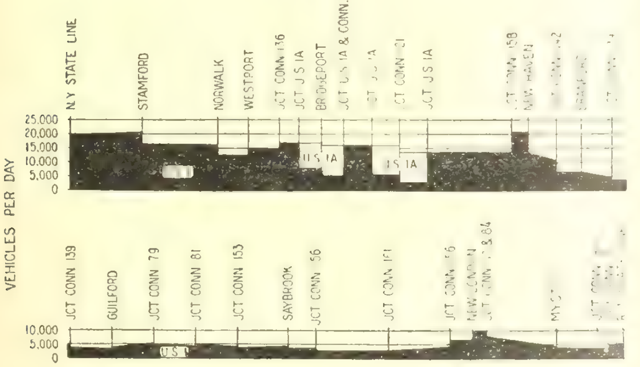

Figure 7.—Variations in Average Daily Traffic Along U S 1 and U S 1A in Connecticut.

traffic; local vehicles are 127 percent of the average week-day traffic; and foreign vehicles are 170 percent of average week-day traffic.

Vehicles registered in States other than Connecticut used the State highways to the extent of 22.6 percent of all recorded traffic. They were much in evidence in all parts of the State, nearly one out of every four vehicles bearing the license of an adjacent or distant State, principally the neighboring States of New York, Massachusetts, and Rhode Island. On the principal through routes U S 1 and U S 5 with their alternates U S 1A and U S 5A, foreign vehicles contributed 33.4 percent of the total vehicle flow, or one in every three vehicles.

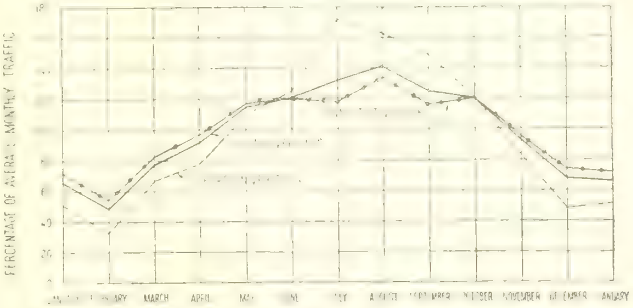

Figure 8.—Monthly Variations in Local, Foreign, and Total Traffic.

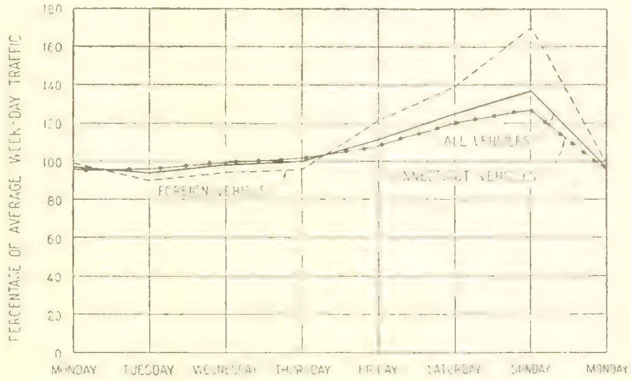

Figure 9.—Daily Variations in Local, Foreign, and Total Traffic. Week-Day Traffic Is Traffic Monday to Friday, Inclusive.

DETAILED DATA OBTAINED FOR TRUCK AND BUS TRAFFIC

Detailed information relating to the characteristics and movement of bus and truck traffic was obtained at 26 selected stations on the principal highways of the State. At least one station was located upon each of the major highways and on more heavily traveled arteries there were several stations. Data were collected on the situs of ownership of the vehicle; its classification as owner operated, contract hauler, or common carrier; the gross load of the vehicle and contents; contact with railroad service; classification of the

TABLE 5.—*Daily variations in traffic density expressed as percentages of average week-day traffic* [1]

	Passenger cars			Trucks			Busses			All vehicles		
	Connecticut	Foreign	Total	Connecticut	Foreign	Total	Connecticut	Foreign	Total	Connecticut	Foreign	Total
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Monday	95	99	96	99	92	98	103	100	103	96	99	97
Tuesday	95	88	93	100	101	100	96	100	96	96	90	94
Wednesday	99	[illegible]	99	95	97	96	98	100	98	99	94	98
Thursday	101	95	99	102	105	102	99	100	99	101	96	100
Friday	109	124	113	104	105	104	104	100	104	108	121	111
Saturday	127	[illegible]	133	90	66	85	102	100	102	120	139	125
Sunday	148	190	158	72	48	35	87	100	87	127	170	137

[1] Week days are Monday to Friday, inclusive.

trip as inter-city, from country to country, or between city and country; and the trip origin and destination. The information was obtained throughout 8-hour periods of operation upon the schedule previously described, and a representative sample of truck and bus traffic was obtained at each station.

It should be understood that the figures presented in this section of the report relate solely to the sample of truck and bus traffic and not to the actual number of individual vehicles of a certain type. For example, if the same truck made 10 trips a day past a recording station, it was counted 10 times in this sample. Because of the possibility of almost unlimited variations in this respect, no attempt should be made to determine from these figures the actual number of separate vehicles of a particular kind or class in the State. It is not the purpose of this analysis to furnish that information. It aims, rather, to present a general cross section of truck and bus traffic as it moved over the highways of the State. Each statement regarding the proportion of a certain class of vehicles in any breakdown refers exclusively to the particular sample of highway traffic under consideration. Therefore, figures or percentages presented in one analysis should not be applied to another without a clear understanding of the nature of both. It will be observed that the size of the sample presented in the different tables varies slightly, owing to the failure of the recorders to obtain all items of information for every vehicle.

TRUCK AND BUS CONTACTS WITH RAILROAD SERVICES DISCUSSED

Table 6 lists the locations where truck and bus data were obtained and shows that but six trucks per thousand contacted railroad stations at any time during the trip. All of the locations at which data were obtained were located outside city limits upon main highways, and the above statement therefore applies only to truck traffic in suburban and interurban areas. A similar examination within cities would undoubtedly show a much higher proportion of trucks contacting railroad services. A great majority of the trucks making railroad contact were operated as common carriers.

About 25 percent of the busses called at railroad stations one or more times per trip, and in certain parts of the State the proportion was much greater. For instance, at the station on U S 8 north of Waterville, 67 percent of all busses were found to have stopped at railroad stations at some time during the trip. At other locations as few as six busses per thousand were found to have contacted railroad services.

DATA ON SITUS OF OWNERSHIP AND TRIP CLASSIFICATION OF TRUCKS PRESENTED

The classification of trucks according to situs of ownership—in cities of 2,500 population or over, in villages having fewer than 2,500 inhabitants, or on farms—is tabulated by stations in table 7. According to this classification, 84 percent of all trucks were city owned, and the remainder were divided about equally between village and farm ownership. The proportion of city-owned trucks was smallest in eastern and northwestern Connecticut. At all but one traffic station city-owned trucks were found to be more than 60 percent of the total truck traffic, and at many stations the number of trucks owned by city dwellers exceeded 90 percent of the total count at the station.

Information obtained from truckers with regard to the origin and destination of truck traffic showed that 94 percent of the trucks operating upon Connecticut highways had either one or both terminals within a city, and that 6 percent were traveling between points in the country. For the purposes of trip classification, cities are localities with 2,500 or more population and the remaining areas are considered country. Of the 94 percent of trucks where one or both terminals were within a city, 65 percent were intercity trips, 15 percent were from city to country, and 14 percent were from country to city.

TRUCKS CLASSIFIED BY TYPE OF OPERATION

Of the total sample of truck traffic throughout the State, about three-fourths were owner-operated (serving owners), the other one-fourth was engaged in commercial trucking as contract haulers and common carriers. Contract haulers make special trips when and where desired, at rates agreed upon by the contracting parties; common carriers follow established routes between fixed points, operate on a regular schedule, and charge standard published rates.

The distribution of trucks among these 3 classes of operation is presented in table 8. The 1 common factor was the preponderance of owner-operated trucks, 64 percent or more of the trucks recorded at each station being used in the business of owners. Although it is difficult to find an indication of general trends in these figures for individual stations, variations within certain ranges for groups of stations are significant. On the 3 most heavily traveled routes, U S 1 west of New Haven, U S 5, and U S 5A—the percentages of trucks operated by owners varied between a low of 63.8 and a high of 76.9 percent. For all stations not on these 3 routes, the range of percentages is between 69.9 and 89.5 percent, or 6 and 13 points higher than the corresponding figures for the former group. From this comparison, it is clear that owner-operated trucks more frequently follow the less-traveled routes; or, conversely, that commercial trucks (contract haulers and common carriers) are found more often on the heavily traveled highways.

TABLE 6.—*Sample of truck and bus traffic on Connecticut highways and contacts with railroad service*

Location of station	Trucks		Busses		Railroad contact				
					Trucks		Busses		Trucks and busses, total sample
	Number	Percentage of total	Number	Percentage of total	Number	Percentage of total trucks	Number	Percentage of total busses	
U S 1, southwest of Greenwich	7,818	89.3	935	10.7	24	0.3	170	18.2	8,753
U S 1, at Darien	6,841	88.9	858	11.1	25	.4	150	17.5	7,699
U S 1, east of Westport	7,480	90.0	829	10.0	25	.3	155	18.7	8,309
U S 1, east of Stratford	9,723	86.2	1,559	13.8	30	.3	454	29.1	11,282
U S 1, west of New Haven	8,097	87.8	1,122	12.2	26	.3	271	24.2	9,219
U S 1, at Branford	4,165	91.7	378	8.3	33	.8	105	27.8	4,543
U S 1, at Madison	3,069	89.0	379	11.0	23	.7	104	27.4	3,448
U S 1, at Saybrook	1,993	92.4	163	7.6	16	.8	38	23.3	2,156
U S 1, west of New London	4,798	90.0	536	10.0	22	.5	86	16.0	5,334
U S 1, at Pawcatuck	2,461	87.9	340	12.1	25	1.0	73	21.5	2,801
U S 5, at Berlin	3,518	83.0	720	17.0	23	.7	337	46.8	4,238
U S 5, north of Thompsonville	2,316	69.7	1,006	30.3	1	[1]	392	39.0	3,322
U S 5A, south of State line	2,181	85.7	364	14.3	18	.8	130	35.7	2,545
U S 7, northeast of Ridgefield	1,555	88.1	211	11.9	6	.4	102	48.3	1,766
U S 6, west of Danbury	1,676	91.5	155	8.5	12	.7	1	.6	1,831
U S 6, at Southbury	1,098	93.0	83	7.0	9	.8	2	2.4	1,181
U S 6, at Plainville	2,464	94.8	136	5.2	12	.5	52	38.2	2,600
Conn. 8, at Naugatuck	3,277	96.5	119	3.5	10	.3			3,396
Conn. 8, north of Waterville	2,091	92.1	179	7.9	21	1.0	120	67.0	2,270
Conn. 8, south of Torrington	2,097	92.8	162	7.2	9	.4	92	56.8	2,259
Conn. 15 and U S 5, south of Montowese	2,890	93.7	194	6.3	22	.8	61	31.4	3,084
Conn. 15, north of Northford	1,590	89.8	181	10.2	14	.8	52	28.7	1,771
Conn. 15, Conn. 2, at Glastonbury	3,479	87.5	496	12.5	10	.3	3	.6	3,975
Conn. 9, at Higganum	1,728	93.7	117	6.3	26	1.6	1	.9	1,845
Conn. 12 and Conn. 14 north of Plainfield	1,783	85.0	314	15.0	42	2.4	12	3.8	2,097
Conn. 12 and Conn. 101, at Putnam	2,981	93.0	226	7.0	54	1.8	3	1.3	3,207
Total at all truck and bus stations	93,169	88.8	11,762	11.2	538	.6	2,899	24.6	104,931

[1] Less than 0.1 percent.

TABLE 7.—*Situs of ownership of trucks using Connecticut highways*

Location of station	City ownership		Village ownership		Farm ownership		Total number of trucks
	Number	Percentage of total	Number	Percentage of total	Number	Percentage of total	
U S 1, southwest of Greenwich	7,351	94.1	246	3.2	212	2.7	7,809
U S 1, at Darien	6,373	93.6	172	2.5	262	3.9	6,807
U S 1, east of Westport	6,954	93.3	202	2.7	300	4.0	7,456
U S 1, east of Stratford	8,588	88.9	643	6.7	432	4.5	9,663
U S 1, west of New Haven	7,093	88.5	335	4.2	590	7.3	8,018
U S 1, at Branford	3,345	80.6	250	6.0	557	13.4	4,152
U S 1, at Madison	1,887	61.9	900	29.5	263	8.6	3,050
U S 1, at Saybrook	1,380	70.6	479	24.5	95	4.9	1,954
U S 1, west of New London	3,335	70.0	830	17.4	599	12.6	4,764
U S 1, at Pawcatuck	1,536	62.6	557	22.7	360	14.7	2,453
U S 5, at Berlin	3,282	93.4	87	2.5	145	4.1	3,514
U S 5, north of Thompsonville	2,089	90.6	75	3.2	142	6.2	2,306
U S 5A, south of State line	1,981	91.0	65	3.0	131	6.0	2,177
U S 7, northeast of Ridgefield	1,051	67.7	294	18.9	208	13.4	1,553
U S 6, west of Danbury	1,225	73.8	201	12.1	234	14.1	1,660
U S 6, at Southbury	640	58.5	274	25.0	181	16.5	1,095
U S 6, at Plainville	2,168	88.2	98	4.0	192	7.8	2,458
Conn. 8, at Naugatuck	3,039	92.8	112	3.4	123	3.8	3,274
Conn. 8, north of Waterville	1,836	88.3	58	2.8	186	8.9	2,080
Conn. 8, south of Torrington	1,775	85.0	91	4.4	222	10.6	2,088
Conn. 15 and U S 5, south of Montowese	1,921	67.2	262	9.2	676	23.6	2,859
Conn. 15, north of Northford	1,092	69.3	199	12.6	286	18.1	1,577
Conn. 15, at Glastonbury	2,811	81.8	195	5.7	430	12.5	3,436
Conn. 9 at Higganum	1,107	64.7	390	22.8	214	12.5	1,711
Conn. 12 and Conn. 14 north of Plainfield	1,308	74.0	315	17.8	145	8.2	1,768
Conn. 12 and Conn. 101, at Putnam	2,483	83.5	194	6.5	298	10.0	2,975
Total at all truck and bus stations	77,650	83.8	7,524	8.1	7,483	8.1	92,657

TRIPS OF ONE-THIRD OF TRUCKS FOUND TO EXTEND OUTSIDE OF STATE

An analysis of the origin and destination of 93,913 trucks is presented in table 9 and in figure 10. A little less than two-thirds of these trucks operated only within the State. About 25 percent of the trucks had only one terminal in Connecticut, and less than 10 percent were traveling between points in other States. The latter group constitutes what is ordinarily called "through traffic." In a similar analysis of New Jersey traffic one truck out of three had either one or both terminals outside the State.

In the majority of cases owner-operated trucks had both origin and destination in Connecticut, while contract-hauler and common-carrier trucks operated to a much greater extent in interstate traffic. Trucks of each class of operation making interstate trips had both terminals outside Connecticut less often than one terminal within and one outside the State, but a relatively greater percentage of commercial trucks had both terminals outside the State. Comparatively few owner-operated trucks passed through Connecticut en route between other States, but about one commercial truck out of five was classed as through traffic.

Table 8.—*Truck traffic on Connecticut highways by class of operation*

Location of station	Owner operator		Contract hauler		Common carrier		Total number of trucks
	Number	Percentage of total	Number	Percentage of total	Number	Percentage of total	
U. S. 1, southeast of Greenwich	5,303	68.0	1,578	20.2	922	11.8	7,803
U. S. 1, at Darien	4,726	69.3	1,265	18.5	832	12.2	6,823
U. S. 1, east of Westport	5,296	71.1	1,505	20.2	651	8.7	7,452
U. S. 1, east of Stratford	7,181	74.2	1,815	18.7	684	7.1	9,680
U. S. 1, west of New Haven	5,691	70.9	1,702	21.2	633	7.9	8,026
U. S. 1, at Branford	3,353	80.7	564	13.6	237	5.7	4,154
U. S. 1, at Madison	2,300	75.2	515	16.8	243	8.0	3,058
U. S. 1, at Saybrook	1,388	69.9	426	21.5	171	8.6	1,985
U. S. 1, west of New London	3,930	82.3	611	12.8	235	4.9	4,776
U. S. 1, at Pawcatuck	1,900	77.6	405	16.6	143	5.8	2,448
U. S. 5, at Berlin	2,434	69.3	767	21.9	307	8.8	3,508
U. S. 5, north of Thompsonville	1,769	76.9	409	17.8	123	5.3	2,301
U. S. 5A, south of State line	1,390	63.8	465	21.4	322	14.8	2,177
U. S. 7, northeast of Ridgefield	1,302	83.7	197	12.7	56	3.6	1,555
U. S. 6, west of Danbury	1,494	89.3	148	8.8	31	1.9	1,673
U. S. 6, at Southbury	944	86.2	108	9.9	43	3.9	1,095
U. S. 6, at Plainville	2,197	89.5	170	6.9	87	3.6	2,454
Conn. 8, at Naugatuck	2,374	72.6	548	16.7	350	10.7	3,272
Conn. 8, north of Waterville	1,619	77.8	299	14.4	163	7.8	2,081
Conn. 8, south of Torrington	1,725	82.3	236	11.2	136	6.5	2,097
Conn. 15 and U. S. 5, south of Montowese	2,323	81.2	419	14.6	119	4.2	2,861
Conn. 15, north of Northford	1,164	73.3	337	21.2	87	5.5	1,588
Conn. 15, Conn. 2, at Glastonbury	2,981	86.3	349	10.1	123	3.6	3,453
Conn. 9, at Higganum	1,535	88.9	129	7.5	62	3.6	1,726
Conn. 12 and Conn. 14, north of Plainfield	1,289	72.7	348	19.6	137	7.7	1,774
Conn. 12 and Conn. 101 at Putnam	2,416	81.2	398	13.4	160	5.4	2,974
Total at all truck and bus stations	70,024	75.5	15,713	16.9	7,057	7.6	92,794

Table 9.—*Truck traffic on Connecticut highways making State and interstate trips, by class of operation*

Origin and destination	Owner operator		Contract hauler	
	Number	Percent	Number	Percent
Both in Connecticut	51,307	72.4	5,908	37.1
1 in Connecticut	16,683	23.5	6,261	39.4
Both outside Connecticut	2,916	4.1	3,743	23.5
Total	70,906	100.0	15,912	100.0

Origin and destination	Common carrier		All classes	
	Number	Percent	Number	Percent
Both in Connecticut	2,836	40.0	60,051	63.9
1 in Connecticut	2,939	41.4	25,883	27.6
Both outside Connecticut	1,320	18.6	7,979	8.5
Total	7,095	100.0	93,913	100.0

The topography of the New England States is such that Connecticut forms a natural and comparatively level thoroughfare for traffic between the eastern seaboard and central valley districts, New York City, and other points to the south and west. The Berkshire Mountains parallel the western boundary of Massachusetts along its entire length, and the Green Mountains of Vermont erect an effective barrier to east and west traffic except at a few points. Accordingly, a considerable part of truck traffic on Connecticut highways was going to or from other New England States and eastern Canada. The flow of truck traffic is clearly shown in table 10 and figure 11.

Owner-operated trucks from New York were going principally to points in Connecticut and other New England States, with a very small percentage passing through Connecticut en route from the New York City metropolitan area to other parts of New York State. In contrast with owner-operated trucks, a smaller proportion of contract-hauler trucks from each of the origins indicated in the table was destined for points in Connecticut.

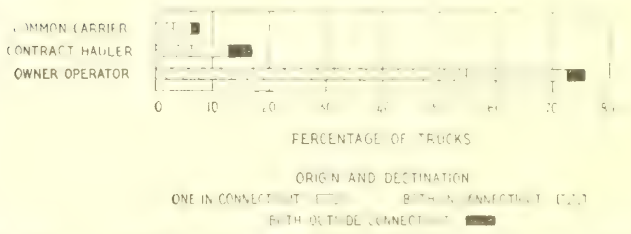

Figure 10.—Truck Traffic Classified by Kind of Trip and Class of Operation.

The proportion of common-carrier trucks originating in New England and bound for New York State was approximately the same as that of contract-hauler trucks, but a greater percentage of common carriers had their destination in Connecticut, and fewer were running to more distant States. Common-carrier trucks from New York also showed a greater proportion stopping in Connecticut and relatively fewer continuing through the State to other parts of New England.

That part of truck traffic on Connecticut highways having one or both terminals within the State may be considered as of primary importance to the State itself. A comparison of the dispersion of truck traffic originating or terminating in Connecticut is presented in table 11. The relative importance of each geographic area as the origin and destination of truck traffic is shown, for each of the three classes of operation, in figure 12. More than 80 percent of this traffic remained within the boundaries of Connecticut, and by far the greater part of the remainder was between Connecticut and other New England States, including a very small amount of traffic with Canada and New York State, principally the New York City metropolitan area. New Jersey claimed a little less than 1 percent of this traffic, and only occasionally were trucks found making trips between Connecticut and Pennsylvania, Delaware, Maryland, Virginia, and the District of Columbia. Trucks to or from more distant States were rarely found. The close parallel between the two series of figures in table 11 again serves to

TABLE 10.—*Truck traffic classified by type of operation and by origin and destination*

Class of operation and destination	Origin of truck traffic															
	New England ¹ and Canada		Connecticut		New York		New Jersey		Pennsylvania		Delaware, Maryland, Virginia, and District of Columbia		Other States		Total	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
OWNER OPERATOR																
New England ¹ and Canada	101	2.2	2,991	5.0	1,186	19.5	189	37.5	67	59.8	77	71.3	42	50.6	4,653	6.6
Connecticut	3,225	71.2	51,307	86.3	4,857	79.8	313	62.1	44	39.3	29	26.9	39	47.0	59,814	84.3
New York	786	17.4	4,745	8.0	40	.7	2	.4	1	.9	2	1.8	1	1.2	5,577	7.9
New Jersey	174	3.9	320	.5	2	(²)									496	.7
Pennsylvania	69	1.5	45	.1											114	.2
Delaware, Maryland, Virginia, and District of Columbia	142	3.1	58	.1	1	(²)									201	.3
Other States	33	.7	17	(²)									1	1.2	51	.1
Total	4,530	100.0	59,483	100.0	6,086	100.0	504	100.0	112	100.0	108	100.0	83	100.0	70,906	100.0
CONTRACT HAULER																
New England ¹ and Canada	60	2.1	1,048	11.8	1,414	43.5	233	46.0	121	66.5	75	74.3	70	64.8	3,021	19.0
Connecticut	1,066	37.2	5,908	66.4	1,817	55.9	269	53.2	59	32.4	25	24.7	32	29.6	9,176	57.7
New York	1,243	43.4	1,560	17.5	13	.4	4	.8	2	1.1	1	1.0	6	5.6	2,829	17.8
New Jersey	287	10.0	254	2.9	1	(²)									542	3.4
Pennsylvania	107	3.7	75	.8											182	1.1
Delaware, Maryland, Virginia, and District of Columbia	67	2.4	31	.3	3	.1									101	.6
Other States	34	1.2	25	.3	2	.1									61	.4
Total	2,864	100.0	8,901	100.0	3,250	100.0	506	100.0	182	100.0	101	100.0	108	100.0	15,912	100.0
COMMON CARRIER																
New England ¹ and Canada	20	2.0	473	11.7	701	37.4	73	52.9	11	40.7	3	60.0	7	53.8	1,288	18.2
Connecticut	461	47.0	2,836	69.9	1,171	62.4	65	47.1	15	55.6	2	40.0	6	46.2	4,556	64.2
New York	431	43.9	685	16.9	2	.1			1	3.7					1,119	15.8
New Jersey	51	5.2	40	1.0	1	.1									92	1.3
Pennsylvania	8	.8	18	.4	1										27	.4
Delaware, Maryland, Virginia, and District of Columbia	8	.8	2	.1											10	.1
Other States	2	.2	1	(²)											3	(²)
Total	981	100.0	4,055	100.0	1,876	100.0	138	100.0	27	100.0	5	100.0	13	100.0	7,095	100.0
ALL CLASSES																
New England ¹ and Canada	181	2.2	4,512	6.2	3,301	29.4	495	43.1	199	62.0	155	72.4	119	58.3	8,962	9.6
Connecticut	4,752	56.7	60,051	82.9	7,845	70.0	647	56.4	118	36.8	56	26.2	77	37.8	73,546	78.3
New York	2,460	29.4	6,990	9.7	55	.5	6	.5	4	1.2	3	1.4	7	3.4	9,525	10.2
New Jersey	512	6.1	614	.8	4	.1									1,130	1.2
Pennsylvania	184	2.2	138	.2	1										323	.3
Delaware, Maryland, Virginia, and District of Columbia	217	2.6	91	.1	4										312	.3
Other States	69	.8	43	.1	2								1	.5	115	.1
Total	8,375	100.0	72,439	100.0	11,212	100.0	1,148	100.0	321	100.0	214	100.0	204	100.0	93,913	100.0

¹ Except Connecticut.

² Less than 0.1 percent.

emphasize the point that traffic between given localities tends to be the same in both directions. The subdivision of this truck traffic according to class of operation is presented in figure 11.

The distribution of through truck traffic according to destination is shown in table 12. The relative importance of each area as both origin and destination of trucks passing through Connecticut is shown in figure 13. Figures 12 and 13 show clearly that trucks engaged in both classes of commercial hauling are found much more frequently in through traffic than in traffic that has its origin or destination in Connecticut.

Trucks having both terminals within Connecticut constituted 63.9 percent of all trucks whose origins and destinations were recorded. Approximately one-third of this intrastate truck traffic was between 15 cities in various localities. Details of this analysis are presented in table 13, and also in figure 14. Owner-operated trucks were more frequently operating between other points than these 15 cities, though many may have had either their origin or destination in one or another of them. Only 28 percent of the entire number of owner-operated trucks in intrastate traffic made their trips between cities enumerated above. Contract haulers were about equally divided in their operation between pairs of these cities and between other points, and only 1 out of 3 common carriers had either or both terminals outside these cities.

Analysis of intercity truck traffic originating in principal Connecticut cities is possible where truck counts were taken at points on the principal routes between them. Ordinarily, the bulk of truck traffic was between neighboring cities, although larger but more distant cities sometimes drew a considerable amount of traffic. Local traffic with nearby places consisted chiefly of owner-operated trucks, a large proportion of these undoubtedly being of the retail delivery class. Traffic to more distant points frequently showed a greater proportion of contract-hauler and common-carrier trucks.

GROSS WEIGHTS OF TRUCKS MEASURED

Scales were available at 11 stations at which the combined weights of the vehicles and loads were obtained. This weight is hereafter referred to as gross weight.

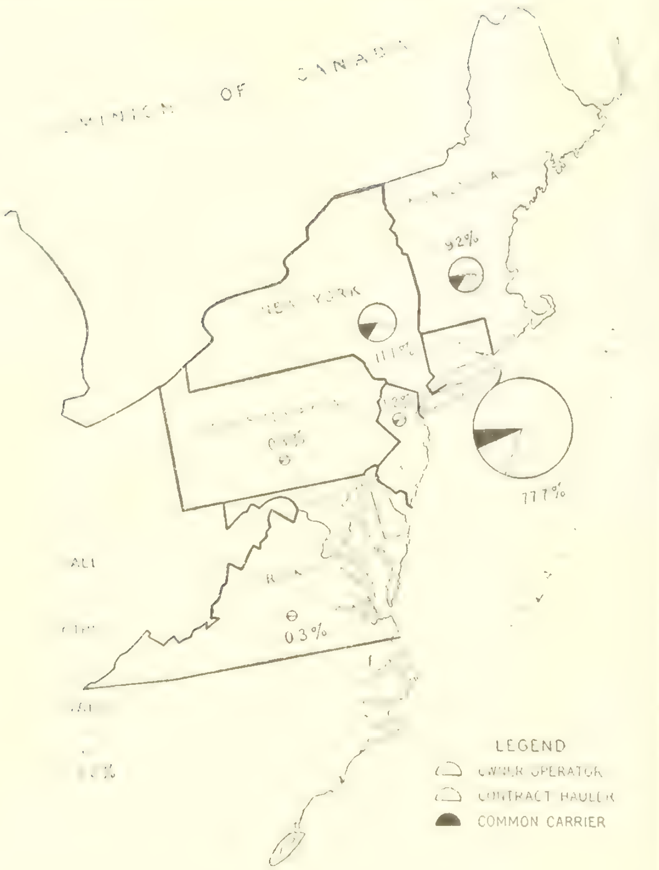

FIGURE 11.—RELATIVE IMPORTANCE OF EACH AREA AS THE ORIGIN AND DESTINATION OF ALL TRUCK TRAFFIC, BY CLASS OF OPERATION. AREAS OF CIRCLES ARE PROPORTIONAL TO PERCENTAGE DISTRIBUTION OF ALL TRUCKS.

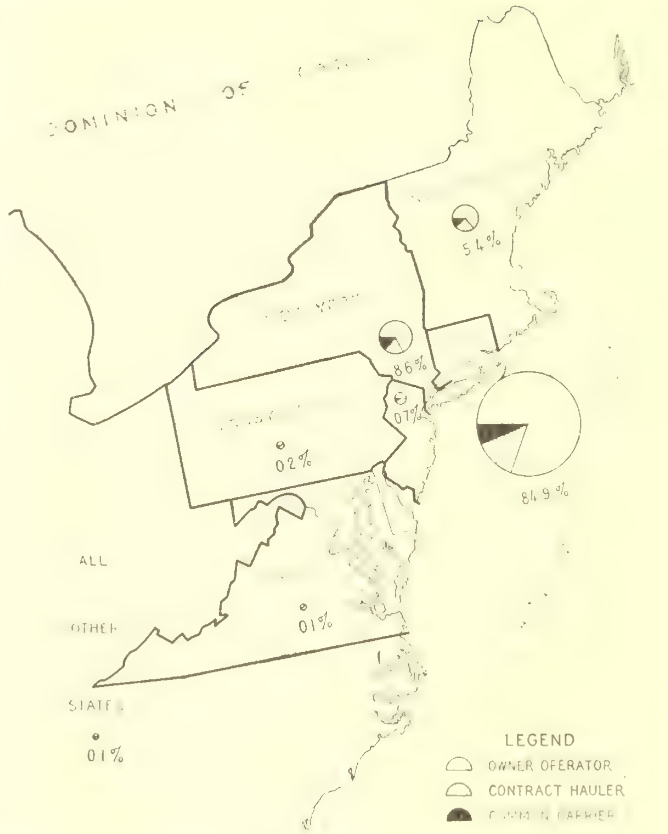

FIGURE 12.—RELATIVE IMPORTANCE OF EACH AREA AS THE ORIGIN AND DESTINATION OF TRUCKS HAVING ONE OR BOTH TERMINALS IN CONNECTICUT, BY CLASS OF OPERATION. AREAS OF CIRCLES ARE PROPORTIONAL TO PERCENTAGE DISTRIBUTION OF ALL TRUCKS.

TABLE 11.—*Origin or destination of truck traffic that originates or terminates in Connecticut*

Origin or destination	Trucks having origin in Connecticut		Trucks having destination in Connecticut	
	Number	Percent	Number	Percent
New England and Canada	4,512	6.2	4,752	6.3
Connecticut	60,051	82.9	60,051	81.7
New York	6,990	9.7	7,845	10.7
New Jersey	614	.8	647	.9
Pennsylvania	138	.2	118	.2
Delaware, Maryland, Virginia, and District of Columbia	91	.1	56	.1
All other States	43	.1	77	.1
Total	72,439	100.0	73,546	100.0

TABLE 12.—*Destination of through truck traffic by class of operation*

Destination	Owner operated		Contract hauler		Common carrier		All classes	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
New England and Canada	1,662	57.0	1,973	52.7	815	61.7	4,450	55.8
New York	832	28.5	1,269	33.9	434	32.9	2,535	31.8
New Jersey	176	6.0	288	7.7	52	3.9	516	6.4
Pennsylvania	69	2.4	107	2.9	9	.7	185	2.3
Delaware, Maryland, Virginia, and District of Columbia	143	4.9	70	1.9	8	.6	221	2.8
Other States	34	1.2	36	.9	2	.2	72	.9
Total	2,916	100.0	3,743	100.0	1,320	100.0	7,979	100.0

1 Except Connecticut.

The locations of these stations, the number of trucks weighed, and the average gross weights at each are shown in table 14.

The weights varied from about 1,000 pounds to as high as 80,000 pounds in the case of a few special vehicles. Light delivery vehicles were classed as trucks, and tractor-semitrailer combinations were weighed as a single unit. The highest average gross weight at any station was 12,100 pounds on U S 5A, south of the Massachusetts State line, and the lowest on Connecticut 12, at Putnam. Generally, high average gross weights were found at stations on U S 1, U S 5 and 5A, the routes on which the greatest traffic density was recorded. The average gross weight of owner-operated trucks was 7,600 pounds; that of contract-hauler trucks, 15,200 pounds; and that of common-carrier trucks, 17,000 pounds; while 9,600 pounds was the average gross weight of all classes of trucks combined. A great majority of owner-operated trucks were in the lower weight groups; only about 20 percent of these weighed 10,500 pounds or over. Among both contract-hauler and common-carrier trucks, however, about two-thirds weighed 10,500 pounds or more.

Trucks on U S 5A south of the State line had the heaviest gross weights and the proportion of contract haulers and common carriers was largest. At Putnam, where the percentage of owner-operated trucks was high, the average gross weight was less than at any other station. In general, average gross weight was greatest where commercial hauling was a high

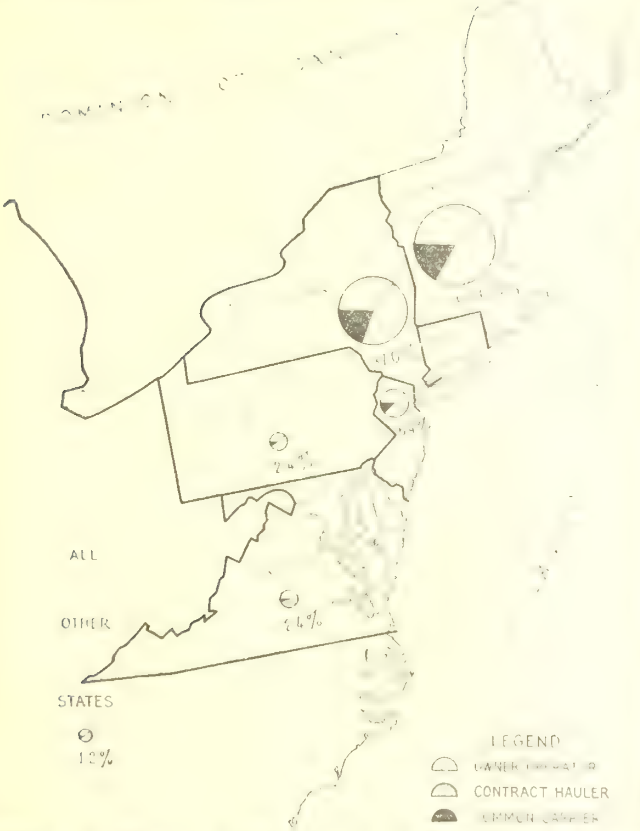

FIGURE 13.—RELATIVE IMPORTANCE OF EACH AREA AS THE ORIGIN AND DESTINATION OF TRUCKS PASSING THROUGH CONNECTICUT, BY CLASS OF OPERATION. AREAS OF CIRCLES ARE PROPORTIONAL TO PERCENTAGE DISTRIBUTION OF THROUGH TRUCKS.

proportion of the total truck traffic and lowest at points where commercial hauling was low in proportion to total truck traffic. Table 15 shows the distribution of the various classes of trucks according to gross weights.

Eighty-two trucks weighed more than 43,500 pounds. Twelve of these were found on U S 1, southwest of Greenwich; 29 on U S 1, east of Stratford; and 18 on U S 5 at Berlin. Thus, about seven-tenths of these trucks were in operation on routes between New York City and New Haven, or between New Haven and Hartford. Several of the heaviest trucks were also found on U S 5 north of Thompsonville, on U S 5A south of the State line, on U S 1 at Saybrook, and on Connecticut 8 at Naugatuck. Three-eighths of these trucks were owner-operated, the other five-eighths being commercial haulers. More than half of these heavy trucks were en route to or from New York City. Three-fourths were engaged in interstate traffic, one-fourth passing through the State, and one-half having one terminal in Connecticut and one outside. In almost every instance these trucks were owned by city residents and were operating between cities.

CHARACTERISTICS OF BUS TRAFFIC DISCUSSED

The distribution of busses according to the principal classifications indicates that more than 96 percent of all busses on Connecticut highways were owned by city residents; about 3 percent were owned by residents of villages or towns of less than 2,500 population; and less than 1 percent were owned by residents of farms. About 82 percent of all busses were traveling between cities; less than 2 percent ran from country to country; and about 16 percent were operating between city and country. Nearly 95 percent of all busses on Connecticut highways were common carriers, and contract-hauler busses were about 5 percent of the total. Tabulations of the origin and destination of individual busses show that 37 percent had both origin and destination in Connecticut; about 26 percent had one terminal in Connecticut and one outside; and 37 percent had both origin and destination in other States. Contract-hauler busses occurred most frequently in intrastate traffic, and least frequently in through traffic.

(Continued on p. 244)

TABLE 13.—*Destination of intercity truck traffic on Connecticut highways by class of operation*

Destination, city and county	Owner operator		Contract hauler		Common carrier		All classes	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Torrington, Litchfield	516	3.6	98	3.5	74	4.0	688	[illegible]
Bristol, Hartford	430	3.0	37	1.3	24	1.3	491	[illegible]
Hartford, Hartford	964	6.7	296	10.6	196	10.7	1,456	[illegible]
New Britain, Hartford	528	3.7	51	1.8	28	[illegible]	607	[illegible]
Bridgeport, Fairfield	3,598	25.0	732	26.2	426	23.2	4,756	25.0
Danbury, Fairfield	228	1.6	27	1.0	21	1.1	276	1.4
Greenwich, Fairfield	198	1.4	28	1.0	22	1.2	248	1.3
Norwalk, Fairfield	941	6.5	91	3.3	60	3.3	1,092	[illegible]
Stamford, Fairfield	1,286	8.9	124	4.5	130	7.1	1,540	8.1
Meriden, New Haven	444	3.1	48	1.7	16	.9	508	2.7
New Haven, New Haven	3,421	23.8	747	26.8	471	25.6	4,639	24.4
Waterbury, New Haven	818	5.7	215	7.7	157	8.5	1,190	6.3
Middletown, Middlesex	382	2.6	99	3.6	39	2.1	520	2.7
New London, New London	511	3.5	163	5.8	138	7.5	812	4.3
Norwich, New London	133	.9	33	1.2	36	2.0	202	1.1
Total, 15 cities	14,398	100.0	2,790	100.0	1,838	100.0	19,026	100.0
Percentage of intrastate truck traffic [1]		28.1		47.2		64.8		31.7

[1] The base figures for these percentages are found in table 10.

TABLE 14.—*Number and average gross weight of trucks passing designated points on Connecticut highways*

Location of station	Trucks weighed	Average gross weight
	Number	*Pounds*
U S 1, southwest of Greenwich	[illegible]	[illegible]
U S 1, east of Stratford	[illegible]	[illegible]
U S 1, at Saybrook	1,970	[illegible]
U S 7, northeast of Ridgefield	[illegible]	[illegible]
U S 5, at Berlin	3,513	11,100
U S 5, north of Thompsonville	1,854	[illegible]
U S 5A, south of State line	2,178	[illegible]
U S 6, at Plainville	2,463	[illegible]
Conn. 8, at Naugatuck	1,847	9,300
Conn. 12 and Conn. 14, north of Plainfield	1,749	[illegible]
Conn. 12 and Conn. 101, at Putnam	1,258	6,600
Total and average, 11 stations	26,148	9,600

TABLE 15.—*Distribution of trucks according to gross weight and by class of operation*

Gross weight, pounds	Owner operator		Contract hauler		Common carrier		All classes		Average gross weight, pounds
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	
Under 4,500	7,742	39.9	232	5.0	62	3.0	8,036	30.8	3,200
4,500 to 10,499	7,857	40.5	1,515	[illegible]	606	29.6	9,978	38.3	6,800
10,500 to 19,499	2,558	13.2	1,637	35.5	696	33.9	4,891	18.8	14,300
19,500 to 29,499	890	4.6	810	17.6	402	19.6	2,102	8.1	23,800
29,500 and over	358	1.8	414	9.0	285	13.9	1,057	4.0	36,700
Total, all weights	19,405	100.0	4,608	100.0	2,051	100.0	26,064	100.0	9,600
Average gross weight	7,600		15,200		[illegible]		9,600		

SOME CHARACTERISTICS OF HIGHWAY TRAFFIC IN RHODE ISLAND

BY THE DIVISION OF HIGHWAY TRANSPORT, BUREAU OF PUBLIC ROADS[1]

DURING the summer of 1934 a survey was conducted on the 725-mile State highway system of Rhode Island to obtain information on the distribution and classification of highway traffic, and the habits of drivers with regard to speed and obedience to traffic regulations. Work was done as a project of the Federal Emergency Relief Administration to furnish employment to many persons on relief rolls throughout the State. The sponsors were the Bureau of Public Roads, the State Board of Public Roads, the Department of State Police, and the Governor's Committee on Street and Highway Safety.

The field data were tabulated by 459 field enumerators at 355 observation stations during the period from June 29 to September 26, under the direction of 16 field supervisors. The administrative work and the compilation and analysis of data were done by a headquarters staff of 64 persons working from June 1 to December 20.

Insofar as possible, all data were classified as follows:

1. By weekdays and Sundays.
2. By hours of the day.
3. By location of the stations with reference to population as follows:

(*a*) Urban, the business centers of communities.

(*b*) Suburban, built-up areas predominantly residential.

(*c*) Rural, open country with houses or stores widely scattered.

It is important to note that only a few miles of the State highway system penetrate the boundaries of large cities, and hence the data obtained does not reflect city traffic conditions.

WEATHER CONDITIONS HAVE GREATEST EFFECT ON SUNDAY TRAFFIC

Observations of weekday and Sunday traffic at 135 stations showed that the Sunday traffic volume exceeded that of the average weekday by 42 percent. The hourly observations disclosed that the greatest traffic for the average weekday was from 5 to 6 p. m., with 7.54 percent of the total traffic volume for the day; and that the next busiest hour was from 8 to 9 p. m., with a nearly equal amount (7.52 percent). The weekday traffic volume dwindled to less than half of 1 percent between 4 and 5 a. m. On Sundays 8.05 percent of the day's traffic volume occurred between 7 and 8 p. m., and less than half of 1 percent occurred between 3 and 4 a. m.

Population density was found to have a definite effect on traffic. At urban stations the traffic volume rose to sharp peaks during the morning rush hour (8–9 a. m.), the late afternoon (5–6 p. m.), and the early evening (8–9 p. m.). Suburban stations showed the same characteristics, but not so strongly emphasized. At rural stations the volume was variable, increasing during the day because of through traffic, and with a peak only in the late afternoon (5–6 p. m.).

The influence of weather on traffic volume was made the subject of a special study carried on at five stations located on the principal routes between cities and coast resorts. Traffic volume was not noticeably affected by rainfall or excessive temperatures during the business hours of week days, but on hot Saturday afternoons and Sundays the volume was greatly increased. Heavy rain on a Sunday morning resulted in a concentration of most of the day's traffic in the afternoon hours, causing much congestion.

In determining the character of highway usage, data were recorded for 2,415,000 vehicles observed at 25 important intersections throughout the State. Counts were made of the numbers of passenger cars, busses, and trucks, the latter being subdivided by rated capacities. Table 1 shows the percentages of the three principal classes of vehicles according to place of registration.

TABLE 1.—*Classification of traffic by type of vehicle and place of registration*

Classification	Rhode Island	Foreign	Total
	Percent	*Percent*	*Percent*
Passenger cars	70.6	19.7	90.[illegible]
Trucks	7.3	1.4	8.7
Busses	.9	.1	1.0
Total	78.8	21.2	100.0

Passenger cars constituted over 90 percent of the total volume of traffic on the State highway system. During the summer of 1934, in addition to the usual summer attractions the presence of a naval fleet at Newport, horse races at Narragansett, and the international yacht cup races drew many visitors from other States. On the average week day 20.4 percent of the passenger cars were from outside the State, and on Sundays the percentage was 24.2.

Trucks constituted nearly 9 percent of the total traffic. The classification of trucks by rated capacity is shown in table 2. Truck traffic on Sundays was about 4 percent of the total traffic volume for the day, while on week days it constituted approximately 10 percent.

TABLE 2.—*Classification of trucks by rated capacity and place of registration*

Rated capacity	Rhode Island	Foreign	Total
	Percent	*Percent*	*Percent*
0 to 1½ tons, inclusive	49.6	5.8	55.4
1½ to 5 tons	25.0	5.2	30.2
5 tons and over	9.2	5.2	14.4
Total	83.8	16.2	100.0

AVERAGE SPEED OF VEHICLES FOUND TO BE 34 MILES PER HOUR

In this survey particular attention was given to the measurement of the speed of vehicles. Vehicles were timed by stop watches over a measured course and their speeds were computed. Nearly 675,000 vehicles were observed at 160 stations over five different periods aggregating 27 days. The average speed of all vehicles was found to be 33.8 miles per hour. Speeds of weekday and Sunday traffic by types of vehicles are shown in table 3.

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[1] The full report has been submitted to the Rhode Island State Board of Public Roads and will not be published or distributed by the Bureau of Public Roads.

Vehicle speeds were relatively high in the early morning business hours, and decreased sharply between 2 and 5 p. m. A marked increase in speed occurred between 5 and 7 p. m., and during the later evening hours the lowest speeds of the day were observed. The most striking decrease, of about 3 miles per hour, occurred at dusk. Speeds again rose to a peak in the small hours of the morning.

The effects of grades and curves and of weather conditions on vehicle speed, as far as could be determined from the data obtained in this study, were negligible. However, the observations were made on sections of road improved according to high standards of design and there were no sharp curves or steep grades.

Foreign cars traveled at speeds averaging 2.1 miles per hour faster than Rhode Island cars. Possibly this was because the drivers of foreign cars were making longer trips and were more concerned with saving time, or perhaps because they had newer or better-conditioned cars.

Unaccompanied drivers drove faster than the drivers with passengers by 1.3 miles per hour. There seemed to be no significant differences in the speeds of cars driven by men and those driven by women.

TABLE 3.—*Average vehicle speeds on week days and Sundays*

Classification	Week days	Sundays	Total
	Miles per hour	*Miles per hour*	*Miles per hour*
Passenger cars	34.4	33.5	34.2
Light trucks	31.2	31.1	31.2
Heavy trucks	28.4	29.4	28.4
Busses	30.5	30.1	30.4
Weighted average	33.9	33.4	33.8

A wide difference of opinion between the State police and the average driver as to safe speeds is indicated by the difference between the speeds observed and the speeds posted on the "safe speed" signs along certain roads by the State police. The percentage of drivers exceeding the posted limits ranged from 10.7 percent at 45-miles-per-hour signs to 86.1 percent at 20-miles-per-hour signs. Observations made at 13 stations showed that 37.7 percent of the drivers drove from 5 to 9 miles per hour faster than the signs indicated, and that 30 percent exceeded the limits by from 10 to 14 miles per hour. It should be noted, however, that under the present laws and regulations such signs are advisory only, and while the rather general disregard of their warnings may be considered as a challenge of the judgment used in placing the signs, it does not indicate a lack of control by the police.

MANY DRIVERS FAIL TO OBEY "STOP" SIGNS

A considerable part of the field work was devoted to the observation of driver habits with reference to traffic control devices. The results showed that 0.77 percent of the drivers and 41.7 percent of the pedestrians crossed intersections against red lights, and 14.1 percent of the pedestrians crossed diagonally.

Studies of observance of caution signals (flashing yellow lights suspended over intersections) were made at nine locations. Practically all vehicles approached the locality of these signals at speeds in excess of 15 miles per hour and were recorded as reducing speed to 15 miles per hour or as failing to reduce speed. The value of these observations is influenced by possible inaccuracies in estimating speed. The records show that 54.8 percent of the drivers on week days and 31.8 percent of the drivers on Sundays exceeded 15 miles per hour while passing the signals, even though at the stations where these counts were made there were 15 percent more drivers on Sunday than on the average weekday.

A study of "stop" sign observance showed that in this respect drivers of commercial vehicles were more careful than drivers of passenger cars. More than 220,000 drivers were observed during 1 week. They were classified as follows: (1) Made full stop; (2) almost stopped, that is, reduced speed to less than 3 miles per hour; (3) entered slow, 3 to 15 miles per hour; and (4) entered fast, over 15 miles per hour. A relatively small number, 6.6 percent, were in the fourth class. Table 4 contains a summary of the observations.

TABLE 4.—*Observance of "Stop" sign by different classes of traffic*

Driver's action	Passenger cars	Commercial vehicles	Total
	Percent	*Percent*	*Percent*
Made full stop	44.1	52.2	44.9
Almost stopped	29.1	27.4	28.9
Entered slow	20.0	15.9	19.6
Entered fast	6.8	4.5	6.6
Total	100.0	100.0	100.0

The percentage of obedience (vehicles made full stop or almost stopped) at urban and suburban stations was much higher than at rural stations, 80.9 percent as compared to 63.9 percent.

CURBS AND NARROW SHOULDERS FORCE TRAFFIC TOWARD CENTER OF ROAD

Rhode Island is probably the only State in which the entire State highway system and many town roads have traffic lanes marked with continuous 6-inch white lines on the road surface. During an 8-day period the behavior of over 622,000 drivers with respect to these lanes was observed, on 4-lane roads at 18 stations, on 3-lane roads at 3 stations, and on 2-lane roads at 23 stations. The results are shown in table 5, and represent lane observance on tangents.

The greater safety of four-lane roads was shown by the low percentage of vehicles driven on the wrong side of the road. However, the greater freedom of movement permitted by four lanes had an undesirable effect shown by the excessive straddling of lanes. Straddling decreased as the traffic volume increased, so it may be concluded that the lane markings are most effective when they are most needed, that is, when traffic is heaviest.

The effect of curbs and shoulders on the observance of traffic lanes was also studied. The observations indicate clearly that mental hazards caused by conditions along the roadside have a marked effect upon the

(Continued on p. 243)

AUTOMATIC PUMPING UNITS FOR UNDERPASSES

Reported by **MARTIN DEUTERMAN**, Junior Civil Engineer, Division of Bridges, Bureau of Public Roads

UNDERPASSES are sometimes used for the elimination of grade crossings in cities and other built-up sections where gravity drainage cannot be obtained. There are locations where an overpass would be built if the most effective way of serving highway traffic were the only factor considered, but other considerations such as the effect on values of adjacent property result in the selection of an underpass.

At some locations a clearance of 14 feet and satisfactory sight distances can be obtained only by placing the structures so that an automatic pumping unit is necessary or more economical than other methods of draining. When deciding between a pumping unit and other methods of draining, it should be borne in mind that if the pumping unit fails to operate during a rainstorm the underpass will be unusable.

Figure 1 shows four underpasses equipped with automatic pumping units.

CAREFUL DESIGN NECESSARY TO INSURE AUTOMATIC OPERATION

The drainage system and pumping unit should have ample capacity to care for all ground water that may be encountered. In many locations that appear dry on the surface ground-water streams are found during excavation. The drainage area served by the pumps may sometimes be reduced by the use of gravity sewers and ditches. In the design of catch-basin inlets intended to divert water from the underpass, special care is necessary to prevent water flowing with considerable velocity from passing by openings intended to intercept it and flowing into the drainage area served by the pumps. This can be prevented by lengthening and depressing the catch-basin opening more than usual. In the drainage system served by the pumping unit, the openings in the gratings over the catch-basin inlets should be small enough to catch all material too large to pass through the pumps. The roadway grades and catch-basin inlets should be designed so that no water stands in the roadway either during or after storms. The road surface should have a crown throughout the underpass and should not be "dished" for center drainage, because of the traffic hazard.

The pump may be placed in the sump or in a dry well adjacent to the sump. Where a dry well is used, the walls should be made as waterproof as practical and a small sump should be placed in the floor of the well. This small sump can be unwatered by a small suction pipe tapped to the main suction pipe, with hand-operated cut-off valves in both the main and small suction pipe.

The suction pipe should be placed below the floor of the sump with the floor of the sump sloping toward it. This arrangement has the advantage that sediment is not allowed to collect on the floor of the sump and the amount of water remaining after the pump cuts off is less. Sediment should not be allowed to collect on the floor of the sump, as it will interfere with the proper working of some types of automatic-control mechanisms. Water remaining in the sump may become a breeding place for mosquitoes. If no ground water reaches the sump between rains and it is practical to tap some nearby water supply, it is good practice to admit water to the sump at such rate as to cause the pump to operate every day or two. This will prevent the water from stagnating, and when the station is inspected the water flow can be increased so as to cause the equipment to operate. The equipment is less apt to stick if it is operated frequently than if it is allowed to stand idle for a long period of time.

The dry-well sump and the main sump may be kept dry between rains by drains in locations where the foundation soil affords suitable drainage.

Suction and discharge pipes of sufficient size and with large radius bends will reduce the friction load on the pump. A pipe 6 to 12 inches in diameter will usually be adequate. Separate supports for the discharge pipe at the floor of the sump or dry well and sometimes at the ceiling are necessary to reduce the eccentric load on the pump base. A check valve should be placed in the discharge line to prevent the water from running the motor backwards when the unit cuts off. If the gravity outfall sewer is located close to the pump house the friction head on the pump will be decreased. The size of the outfall pipe should be sufficient to carry the maximum output of the pumps without pressure. It is preferable to have the discharge pipe empty into a manhole, but if the discharge goes directly into the outfall pipe, a reducer long enough to prevent excessive turbulence should be used.

The pumping units usually used are the vertical centrifugal or turbine types designed for handling water conveying trash and suspended matter and capable of passing a sphere of a specified diameter. The specified diameter of the sphere is usually about 1 inch less than the diameter of the pump discharge for discharges up to 6 inches, and about 2 inches less for discharges over 6 inches. A unit will be required with a capacity at least great enough to discharge the maximum run-off of the drainage area into the gravity outlet against the maximum head, including friction head.

The pump should be of sturdy construction, made by a reliable manufacturer, and should be mounted on a rigid cast-iron base that can be bolted to a concrete foundation. A pump with parts easily accessible and removable will reduce the cost of cleaning, repairing, and replacement. The suction elbow should be supplied with an easily removable cleanout plug.

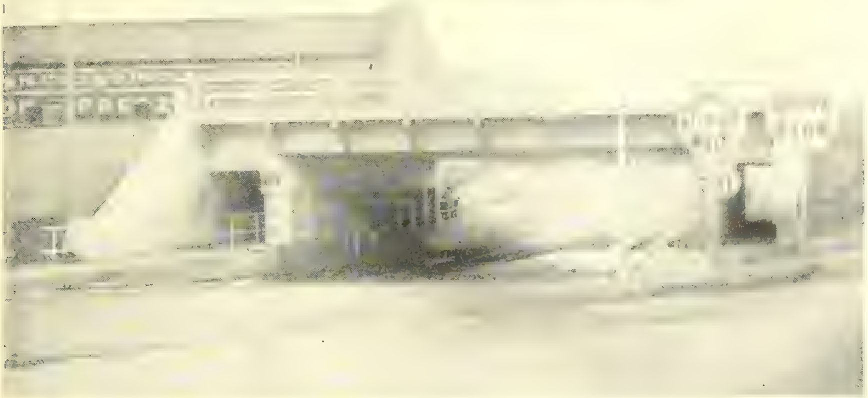
The shaft connecting the pump to the motor should be large enough to operate the pump at all times without whip or vibration. Lateral shaft supports should be placed at intervals of not more than 5 feet. The shaft should have a flexible connection at the pump and rigid connections at other joints. An additional flexible connection just below the motor will prevent any errors in alignment of the bearings from causing the motor to wobble.

CAREFUL ADJUSTMENT AND FREQUENT INSPECTIONS NECESSARY TO AVOID FAILURE DURING STORMS

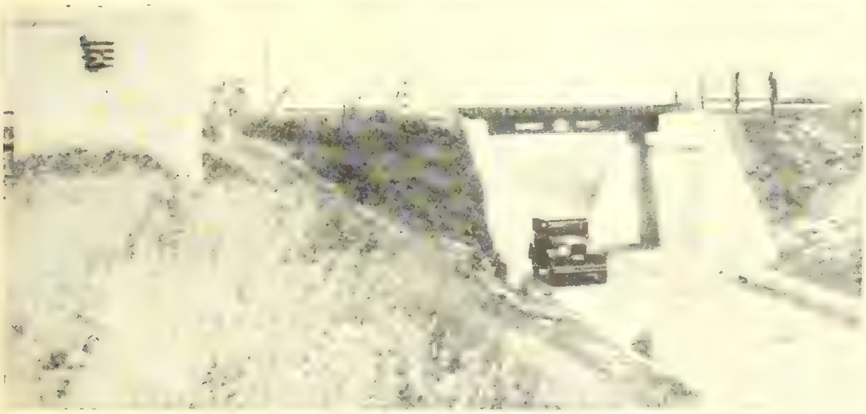
There should be a radial bearing in the motor, one in the pump, and one at each lateral support of the

An Underpass Under Construction in Bowie County, Tex. The Pump House Is Under the Left Span.

An Underpass in Pinal County, Ariz.



An Underpass in Adams County, Nebr. The Pump House Is Behind the Right Abutment.



An Underpass in Harris County, Tex. The Pump House Is Shown in the Upper Left.

Figure 1.—Typical Underpasses Requiring Drainage by Pumping. Note Water Standing in Roadway in Three of the Pictures.

shaft. In addition, there should be a combination thrust and radial bearing in the motor to carry the weight of the revolving parts above the flexible connection, and also one in the pump to carry both the weight of the revolving parts below the flexible connection and the hydraulic thrust of the pump. If an additional flexible connection is used just below the motor, another thrust bearing will be required to carry the weight of the shaft. It is preferable to place this thrust bearing in the base of the motor. The bearings will require a lubrication system that will keep them bathed continuously in oil or grease, the lubrication system being serviced from the control house. With the pump in a dry well the pump bearings and the lowest shaft bearing should be capable of functioning properly while submerged. With the pump in a sump all the bearings that would be under water if the pumps failed to operate during a storm should be capable of functioning property while submerged.

The power unit should be a standard-make electric motor capable of starting and operating the pump under maximum load, without overheating, with the electrical power available. The motor should be of the vertical-shaft type, dust and dirt proof, and should have a rigid base for properly bolting it to the control-house floor. Undervoltage or overload protection should be provided. If two or more pumps are used an automatic alternator will be required that will transfer the operation from one pump to another or allow as many pumps to operate as are required to care for the water.

The automatic control device may be of the float, mercury-switch, or any other type that will give satisfactory service. The device should be set to start the motor after the water is high enough to prime the pump and to stop the motor when the water surface is as low as it can be gotten with the automatic device used or before it reaches the intake of the suction pipe. The adjustments of the control device should be such that it could be set to start and stop the motor at any desired head of water in the sump within practical limits. In the float type of control sediment accumulating under the float may prevent it from getting low enough to cut off the motor. Sediment accumulated around the lower end of the tube that actuates the mercury-switch type of control may prevent a change in pressure in the tube and may cause the device to fail to operate. A manually operated switch should be installed in addition to the automatic switch.

The control house, sump, and dry well should be constructed with doors, windows, trap doors, manholes, and ladders arranged so as to facilitate installation, inspection, and repair of the pumping unit and fittings. The control room should be ventilated with louvers in opposite walls. The elevation of the control room should be such that if the pump fails to operate the room will not be flooded.

The plans and specifications for the equipment and installation should be prepared by a competent engineer. The plans should show the general construction and sectional views of the pump together with characteristic curves showing capacity, efficiency, brake horsepower, and other data necessary to determine the quality of the materials used and the fitness of the apparatus for the service intended.

All electrical equipment and installations should conform to the code of the National Board of Fire Underwriters.

After completion of the installation in every detail, it should be tested by filling the sump and allowing the unit to operate as planned. This test should be repeated until all defects are corrected and adjustments made. It is advisable to make acceptance of the station subject to satisfactory performance during these tests.

Regular inspections should be made to insure the proper operation of an automatic pumping station.

Table 1 lists pertinent data for a number of pumping-station installations.

In May 1935 reports were made to the Texas State Highway Department by its division engineers on the functioning and adequacy of installations made in recent years. These reports gave the following data for some of the Texas projects listed in table 1.

NRM 474, Bowie County.—The type of control that requires that the bottom of the sump house be kept perfectly clean and free from mud is unsatisfactory. Very often the mud is not cleaned out and the switch fails to operate.

The pump operates properly, but during heavy rainstorms the underpass has been flooded to a depth of about 3 feet, closing the underpass to traffic. The pump lacks the capacity to dispose of the water fast enough during heavy rains.

The sewer inlets at a nearby street intersection do not carry as much water as they might, because of the grade of the street and the size of the grate openings. If the grates could be replaced by grates with larger openings, much more water would be diverted from the pump house.

NRM 417–E, Colorado County.—The unit has operated satisfactorily with one exception when power service was interrupted by an electrical storm. The equipment has been given several very thorough tests during heavy rain storms.

The pumping unit has a sump and dry well separated by a concrete wall. The intake of the pump is placed higher than the bottom of the sump, and the electrical starting and stopping device is so set that the pump does not start until there is approximately 28 inches of water in the sump, or sufficient water to prime the pump. After the pump has stopped this water remains in the sump and deposits silt on the bottom. In future installations the intake of the pump should be placed below the elevation of the sump and the bottom portion of the sump should be constructed so as to form a tapered section or funnel shape. This would cause any sediment that might be deposited in the sump to be carried out through the pump. In this way the sump would be dry except during rain storms and the pump would prime itself as soon as sufficient rain water accumulated.

SP 973–B, Fort Bend County; *NRM 512–J, Harris County*; *FAP 514–D, Harris County*; *FAP 565–B, Harris County*; and *NRM 535–E, Harris County.*—When these pumping units were first installed, it was difficult to adjust the automatic control mechanisms properly. Only after 3 to 4 hard rains were the adjustments properly made. After the equipment was once properly adjusted, it seldom failed to work and then failure was usually caused by lightning or wind causing current failure. These pumping units have adequately handled the rain water from all storms that have occurred since installation of the pumps.

SP 873–B, unit 3, Navarro County.—This pumping unit has functioned properly and has given satisfactory service.

TABLE 1.—*Typical pumping-station installations*

Project location and no.	Date of contract or estimate	Type of motor	Size of pump	Cost of equipment	Cost of maintenance
Bowie County, Tex., NRM 474.	Feb. 12, 1934	7½-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Mercury switch control.	[illegible],000 gallons per minute against 11-foot head, 6-inch vertical centrifugal type with 8-inch suction and capable of passing a 4-inch sphere.	$1,[illegible]. Includes sump, motor house, pump, motor, and other appurtenances required for receiving and discharging water.	Minimum rate $1 per month. In last 5 months meter has registered 100 kilowatt-hours at $0.02 per kilowatt-hour. 1 gallon of oil and 1 quart of compression grease bought in April 1935.
Colorado County, Tex., NRM 417-E.	do	7½-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Mercury switch control.	700 gallons per minute against 21-foot head, 6-inch vertical centrifugal type with 8-inch suction and capable of passing a 4-inch sphere.	$2,100. Includes pump, motor, and other appurtenances required for receiving and discharging water.	Average cost, $[illegible] per month.
Fort Bend County, Tex., SP 973-B.	Feb. 19, 1934	15-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Float control.	[illegible] gallons per minute against 23-foot head, 5-inch vertical centrifugal type with 6-inch suction and capable of passing a 4-inch sphere.	$2,100. Includes pump, motor, switch floats, pipes and fittings connected with pump, and motor.	Average cost, $21 per month.
Harris County, Tex., NRM 512-J.	Installed in 1932.	15-horsepower. Mercury switch control.	[illegible],000 gallons per minute against 33-foot head.	$3,000. Estimated replacement cost.	Do.
Harris County, Tex., FAP 514-D.	Feb. 27, 1931	15-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Float control.	[illegible],000 gallons per minute against 22-foot head, 5-inch vertical centrifugal type with 6-inch suction and capable of passing a 4-inch sphere.	$2,660. Includes motor, motor house, pump, well, and sump.	Do.
Harris County, Tex., FAP 565-B.	Aug. 1, 1931.	15-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Mercury switch control	[illegible],000 gallons per minute against 22-foot head, 5-inch vertical centrifugal type with 6-inch suction and capable of passing a 4-inch sphere.	Manhole covers $57, automatic pumping unit $2,400, motor-house door $15, cost of well and other work $3,338, total $5,810.	Do.
Harris County, Tex., NRM 535-E.	Jan. 8, 1934	20-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system Mercury switch control	[illegible],000 gallons per minute against 20-foot head, 6-inch vertical centrifugal type with 8-inch suction and capable of passing a 4-inch sphere	Motor house, dry well, and sump $2,100, automatic pumping unit $2,150, total $4,250.	Division engineer did not make a report of cost, $25 per month assumed to be in line with costs of other installation in same division.
Navarro County, Tex., SP 873-B unit 3	Sept. 21, 1931.	15-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Float control.	1,000 gallons per minute against 20-foot head, 5-inch vertical centrifugal type with 6-inch suction and capable of passing a 4-inch sphere	Automatic drainage unit $1,850, well and other work $2,095, total $3,945.	Average cost $13 per month.
Taylor County, Tex., NRM 581.	Contract not awarded to date	25-horsepower, 3-phase, 60-cycle, 220-volt. Self-contained oiling system. Mercury switch control.[1]	3,000 gallons per minute against 24-foot head, 8-inch vertical centrifugal type with 8-inch suction and capable of passing a 4-inch sphere.	Automatic pumping unit $3,000, motor house $350, concrete for dry well $1,126, total $4,476.	
Pinal County, Ariz., NRS 100-C.	Jan. 23, 1935 (date of estimate).	2 motors, 3-horsepower each, 40° rating, line start, induction, 3-phase, 60-cycle, 220-volt. Motor, shaft, and pump lubricated by electrically operated automatic oiler. Float control.	2 at 250 gallons per minute each against 35-foot head (static 20 feet, friction 15 feet). 4-inch vertical centrifugal or turbine type capable of passing a 3-inch sphere.	$3,100. Includes pump house, sump, dry well, and equipment in place.	
Adams County, Nebr., NRM 169-B.	Mar. 16, 1934.	20-horsepower, 3-phase, 60-cycle, 220-volt. Induction type. Float control.	1,500 gallons per minute against 20-foot head at 850 revolutions per minute, vertical, single-stage, open-impeller type. 8-inch suction and discharge capable of passing a 2-inch sphere. Pump suspended by discharge pipe and pipe enclosing shaft.	Pump house $808, pump and electric wiring $3,600, total $4,408.	

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[1] This particular installation will not be made but the data are given as being typical.

(Continued from p. 239)

TABLE 5.—*Lane observance on tangents*

Driver's action	4-lane roads	3-lane roads	2-lane roads
	Percent	*Percent*	*Percent*
Drove in first lane	57.5	84.7	92.8
Straddled line	29.3	9.1	
Drove in second lane	11.9	6.2	
Drove left of center line	1.3		7.2
Total	100.0	100.0	100.0

TABLE 6.—*Traffic classified by lane observance on hills and curves*

Roads	Stayed in first lane		Crossed center but did not pass		Passed other vehicle	
	Hills	Curves	Hills	Curves	Hills	Curves
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2-lane	93.4	93.7	2.8	4.8	3.8	1.5
3-lane	88.9	73.1	2.4	24.3	8.7	2.6
Combined	92.5	89.8	2.7	8.5	4.8	1.7

driver. Wide shoulders induced traffic to stay in the outside lanes; narrow shoulders increased the tendency to straddle; and permanent raised curbs not only caused straddling, but tended to cause the motorists to drive completely out of the correct lanes.

The dangerous practice of passing on hills and curves was studied during two periods of 6 and 4 days each, 269,000 drivers being observed at 13 hill and 13 curve stations on 2- and 3-lane roads. The results are summarized in table 6.

NEARLY ALL VEHICLES FOUND TO OBSERVE VEHICLE LIGHT REQUIREMENTS

Rhode Island regulations require that every motor vehicle must show 2 headlights and 1 taillight beginning one-half hour after sunset. Observations were made for 8 successive days during the hours from 8 to 10 p. m. Of the 79,200 cars observed, only 3.5 percent violated this law in any degree. The results of this study are shown in table 7.

The greatest percentage of cases where no headlights were shown occurred during the hour from 8 to 9 p. m.,

TABLE 7.—*Traffic classified by lights displayed during different intervals at night*

Lights displayed		8 to 9 p. m.	9 to 10 p. m.	Total 8 to 10 p. m.
Head	Tail			
		Percent	*Percent*	*Percent*
2	1	95.27	98.13	96.47
2	0	1.75	1.12	1.61
1	1	.61	.69	.52
1	0	.06	.02	.04
0	1	.77	.02	.46
0	0	1.54	.02	.90
Total		100.00	100.00	100.00

indicating that some of the drivers were slow in turning on their lights.

Drivers observed at urban and suburban stations made a much better record than those passing rural stations, as may be seen from the following percentages of lighting violations: Urban, 2.7 percent; suburban, 2.6 percent; and rural, 4.3 percent.

The survey's value as an unemployment relief project is shown in the cost figures. The total cost of the survey was $89,961.76, and of this sum $85,342.49, or 94.87 percent, were paid as wages and salaries. The employment provided aggregated 159,135 man-hours.

(Continued from p. 237)

Traffic volume at 54 points on the Connecticut highway system increased 255 percent between the traffic surveys in 1922–23 and 1933–34, exceeding the rate of increase in gasoline consumption over the same period. Traffic has increased more rapidly on the State highway system than upon all roads in the State. New and shorter routes with better pavement and alinement, longer sight distances, and easier grades have caused some shifting of traffic from old routes, but in no instance is a State route carrying less traffic at present than it carried during the 1922–23 traffic survey.

A total of 1,786 miles of trunk-line and State-aid highways have been classified on the basis of present traffic as follows: Sections carrying 1,500 or more vehicles per day, major class; sections carrying 500 to 1,499 vehicles per day, medium class; and sections carrying less than 500 vehicles per day, minor class. Almost 913 miles, or 51 percent, are in the major class; 660 miles, or 37 percent, are in the medium class; and 213 miles, or 12 percent, are in the minor class.

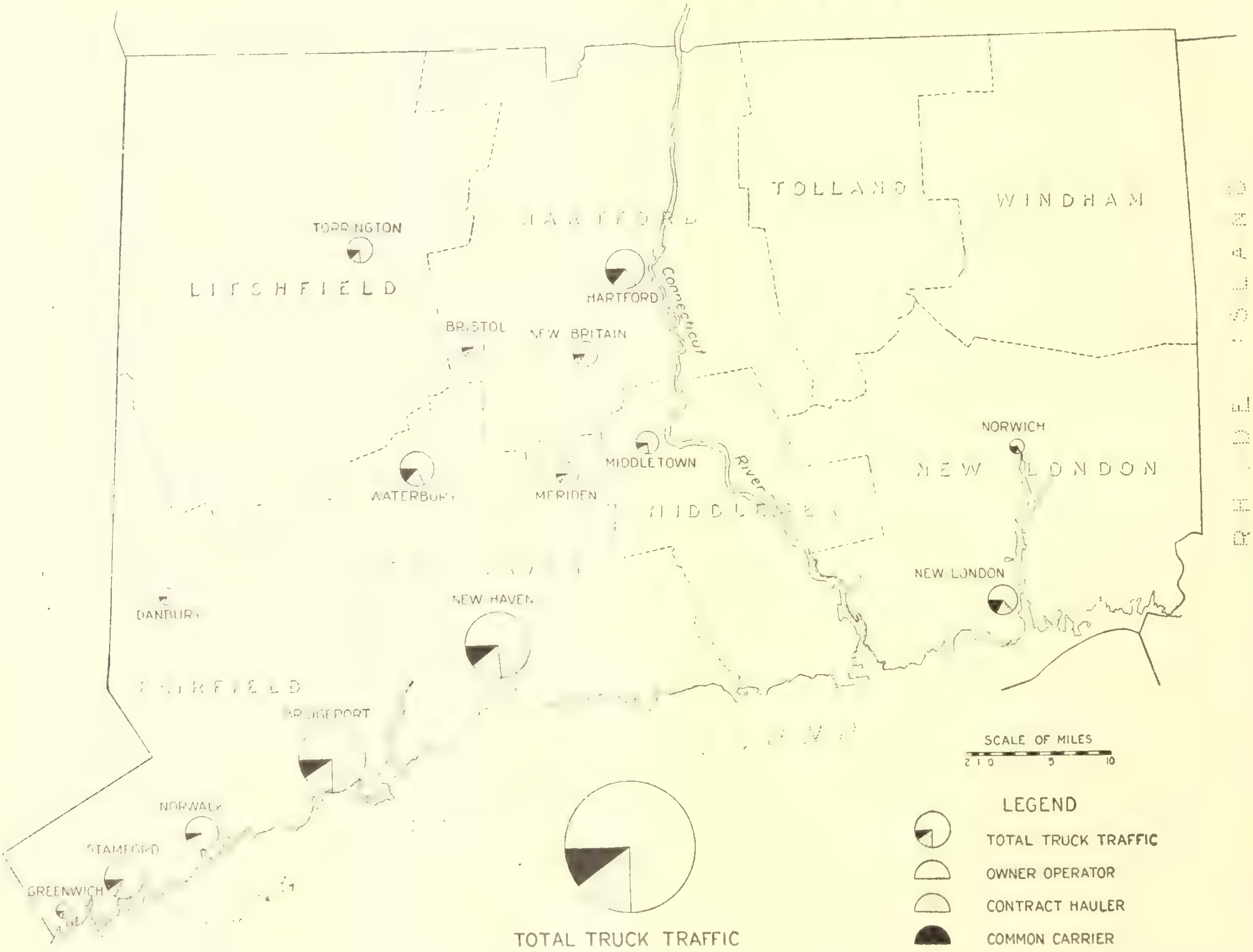

FIGURE 14.—DISTRIBUTION OF INTER-CITY TRUCK TRAFFIC TERMINATING IN 15 PRINCIPAL CITIES OF CONNECTICUT, BY CLASS OF OPERATION. AREAS OF CIRCLES ARE PROPORTIONAL TO PERCENTAGE DISTRIBUTION OF TOTAL TRUCK TRAFFIC BETWEEN THESE 15 CITIES.

COMPLETE CANVASS OF MOTOR-VEHICLE TRANSPORTATION TO BE MADE

By Ralph L. Dewey, Chief, Transportation and Communications Divisions, Census of Business

The Census of Business, covering the calendar year 1935, enumeration for which began January 2, 1936, is the most comprehensive project of its kind ever undertaken, and will for the first time include motor-vehicle operations for hire.

Comparable projects have been completed in other years, but they were limited. In 1930, a census of distribution covering 1929, was taken. In 1934 a census of American business for 1933 was made, but it was limited to distribution, service businesses, amusement enterprises, and hotels.

The rapid change in our entire economic structure has created a demand on the part of business leaders for more complete data concerning the activities of American business. Requests from business men and chambers of commerce determined the scope of the work. Representative organizations in all business fields are working with the Census Bureau to make the project of maximum value.

KIND OF MOTOR TRANSPORTATION INFORMATION TO BE COLLECTED

Kind of business.—A complete canvass of commercial motor-vehicle transportation will be made. This will include both the transportation of commodities and persons. Both freight and passenger carriers will be classified as doing either a local, intrastate, or interstate business. The area covered will determine the classification of a given carrier. A local carrier will be one operating within a given city and the immediately surrounding area, even though a State line may be crossed. Operations between Philadelphia, Pa., and Camden, N. J., Chicago, Ill., and Whiting, Ind., Cincinnati, Ohio, and Covington, Ky., and similar operations will be considered local. A distinction will also be made between contract and common carriers for both bus and truck operators.

Operating revenue and expenses.—Data for total operating revenue and expenses of commercial motor-vehicle operators for 1935 will be collected. Revenue will be classified according to the type of services rendered. Thus revenue received from warehousing and storage, terminal operations, transportation of persons, transportation of commodities, etc., will be listed separately. Expenses will not be allocated on the same basis but rather collected in terms of total expenses for the year. Pay-roll data, however, will be collected separately from all other operating expenses.

Detailed employment data for a sample week (that ending nearest Oct. 26, 1935) will be collected. These will include the number of full-time and part-time employees and the pay rolls for each. Employees will be classified in terms of functions performed such as office and clerical, warehousing and platform, transportation crews, maintenance, servicing, etc.

Inventory of equipment.—A complete inventory of equipment will be obtained. In the case of trucks the number and age of trucks, semitrailers, trailers, and tractors in operation or available for operation in October 1935 will be listed. The first three of these types will be classified by capacities. For motorbusses the number and age of sightseeing, school, and other busses will be obtained. These will be grouped according to capacities.

Value of the survey.—The survey of the motor transportation-for-hire business will be only one aspect of the 1935 Census of Business. Other business enterprises covered by this census will include:

Retail trade.
Wholesale trade.
Construction.
Hotels.
Amusements.
Business services.
Operation of nonresidential buildings.
Advertising agencies.
Nonprofit organizations.
Warehousing.
Broadcasting.
Distribution of manufacturers' sales (channels of primary distribution).
Insurance (carriers, agents, and brokers).
Real estate (agents and brokers).
Banking and finance.

For all these fields of business endeavor the number of establishments, sales, number of employees, pay rolls, etc., will be obtained. All such data will be collected and published by important geographical areas. The position of motor transportation in this picture will be readily ascertainable. A careful analysis of these data should provide a partial index to motor transportation possibilities in given areas. The transportation industry should be highly interested in obtaining an accurate picture of the character and extent of commercial motor-vehicle transportation.

Many values of this survey will prove themselves as the data are collected and made public. While absolutely no information will be given out which will disclose the identity of any individual operator, the combined reports of a number of operators in a given territory will provide an excellent statistical picture of the industry. These data can be coordinated and correlated with the information received from other parts of the Census of Business Survey.

Field work for the census began January 2, 1936. Headquarters for the project have been set up in Philadelphia, where Fred A. Gosnell, experienced head of the previous business census, is chief statistician in charge.

Only sworn employees of the Bureau of the Census are permitted to examine the individual returns. No access to them is permitted under the law, not even to other governmental agencies, and no information will be disclosed which would reveal any of the facts or figures in the returns.

Such a complete survey of business could not be more timely and useful than the one covering 1935. Every effort will be made to expedite reports so as to make available the maximum useful information with a minimum of delay.

The field work will be completed within 3 months after the enumeration starts. The first preliminary report of basic facts, by States, will be issued about July 1, 1936. Soon after the State reports are completed, special statistics for retail trade will be released as rapidly as possible.

CURRENT STATUS OF FEDERAL-AID HIGHWAY PROJECTS

(1936 FUNDS ONLY)

AS OF DECEMBER 31, 1935.

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	FEDERAL AID	Miles	Estimated Total Cost	FEDERAL AID	Miles	Estimated Total Cost	FEDERAL AID	Miles	
Alabama	2,604,320										2,604,320
Arizona	1,781,347				1,489,399	1,230,652	91.1	406,813	320,205	10.1	230,490
Arkansas	2,142,723										2,142,723
California	4,756,959				2,992,047	1,726,449	38.9	320,279	181,106	7.0	2,849,404
Colorado	2,288,811				1,081,206	605,491	45.6	900,777	504,435	37.6	1,178,885
Connecticut	791,253										791,253
Delaware	609,375							422,476	209,443	38.2	399,932
Florida	1,655,723				674,678	337,339	23.8	218,968	109,484	8.7	1,208,900
Georgia	3,168,221				596,164	298,082	36.8	1,290,511	639,030	74.9	2,231,109
Idaho	1,531,162	305,432	172,421	44.6	994,494	593,012	95.0	64,242	38,443	6.0	727,286
Illinois	5,160,696				2,548,483	1,274,241	54.4	3,201,534	1,600,767	55.0	2,285,688
Indiana	3,087,613	216,137	108,068	6.9	3,044,219	1,518,253	93.7	2,120,741	1,060,271	49.9	401,021
Iowa	3,231,718	84,196	39,510	21.0	3,885,848	1,830,615	203.4	2,088,229	984,158	80.7	377,435
Kansas	3,317,054				365,452	182,726	96.2	2,450,186	1,225,093	268.3	1,909,235
Kentucky	2,304,143				1,995,762	978,299	130.1	1,347,108	637,649	50.5	688,195
Louisiana	1,776,939				849,060	424,530	32.0	1,308,524	654,262	44.5	698,147
Maine	1,090,167	113,605	56,803	2.1	1,597,412	798,705	49.6	99,529	49,765	1.9	184,894
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877										1,741,877
Michigan	3,837,292	722,100	361,050	20.7	3,201,374	1,597,962	131.1	1,574,450	787,225	66.5	1,091,055
Minnesota	3,423,306	334,238	143,116	12.2	2,569,078	1,062,579	141.6	1,041,761	396,720	73.2	1,820,891
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,171,810	585,905	220.8	2,615,159	1,307,580	104.7	924,387	462,193	42.9	1,445,178
Montana	2,560,449	558,560	312,738	131.1	1,071,574	599,974	95.1	227,137	127,174	13.8	1,520,563
Nebraska	2,581,663	983,386	491,693	61.4	739,320	369,660	73.2	11,828	5,914	5.2	1,714,396
Nevada	1,595,501	121,853	105,488	55.4	883,442	764,796	95.8				725,217
New Hampshire	609,375				696,758	341,926	18.1	122,782	61,341	3.8	206,108
New Jersey	1,675,751	37,143	18,572	.8	1,286,489	643,244	23.4	2,090,803	997,177	16.2	16,758
New Mexico	1,999,299	67,052	40,781	10.9	1,152,918	701,204	103.2	822,657	500,340	49.2	756,974
New York	6,150,106				7,023,455	3,497,900	130.6	2,695,250	1,302,600	41.5	1,349,606
North Carolina	2,938,657				1,091,425	545,712	183.5	75,887	37,944	15.1	2,355,001
North Dakota	1,960,162										1,960,162
Ohio	4,565,435				449,762	224,782	4.7	2,684,400	1,341,200	35.5	2,999,453
Oklahoma	2,947,521				1,498,396	787,407	50.5	335,155	176,124	11.6	1,983,990
Oregon	2,044,633				2,181,086	1,323,308	86.5	255,447	149,075	4.2	572,250
Pennsylvania	5,348,062	18,018	9,009	.5	3,142,790	1,571,395	47.2	2,992,143	1,495,817	41.7	2,271,841
Rhode Island	609,375										609,375
South Carolina	1,692,896										1,692,896
South Dakota	2,036,775				516,746	283,332	35.2	67,989	37,278	9.9	1,716,165
Tennessee	2,638,159				834,404	417,202	40.5	511,461	255,730	18.4	1,965,227
Texas	7,777,504	3,545	1,700	.3	4,948,085	2,456,912	290.4	2,424,916	1,204,039	120.9	4,114,853
Utah	1,410,752	267,727	193,299	17.0	505,349	364,862	46.8	41,334	29,843	3.3	822,748
Vermont	609,375	25,988	12,994	2.9	1,109,330	554,626	51.3	52,043	26,021	4.7	15,734
Virginia	2,278,475				53,810	26,905	1.5	1,224,568	612,284	44.2	1,639,286
Washington	1,949,957	637,524	335,800	18.8	946,043	498,700	40.3	859,991	451,049	11.7	664,408
West Virginia	1,356,793	87,161	43,581	3.0	493,994	246,997	29.1	58,840	29,420	.2	1,036,795
Wisconsin	3,045,557	230,339	115,169	4.8	1,030,747	501,912	52.5	699,444	330,939	27.5	2,097,537
Wyoming	1,559,444	509,889	314,034	82.2	1,860,381	1,145,789	174.6	140,744	86,683	17.9	12,938
District of Columbia											
Hawaii	609,375							234,328	116,892	2.5	492,483
TOTALS	121,875,000	6,495,703	3,461,731	717.4	64,016,139	33,635,060	3,042.0	38,409,662	19,235,133	1,414.9	65,543,076

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31, 1935.

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	4,151,115				615,359	615,359	24.9	2,732,155	2,732,155	79.8	803,601
Arizona	2,569,341				917,399	897,436	59.8	697,097	624,074	45.1	1,048,331
Arkansas	3,352,061				646,613	645,439	50.1	1,207,825	1,206,181	93.1	1,500,441
California	7,747,928				410,823	383,416	18.2	4,773,890	4,553,271	175.4	2,811,241
Colorado	3,395,263				586,514	586,124	48.0	494,445	494,445	20.5	2,314,695
Connecticut	1,418,709										1,418,709
Delaware	900,310							445,616	445,616	41.6	454,694
Florida	2,597,144				415,255	415,255	9.3	736,132	736,132	30.6	1,445,757
Georgia	4,988,967							483,241	483,241	29.0	4,505,726
Idaho	2,222,747				454,462	440,137	36.0	627,088	579,472	57.4	1,203,138
Illinois	8,694,009				1,695,208	1,695,208	71.4	2,983,335	2,983,335	220.1	4,015,466
Indiana	4,941,255				575,619	575,619	34.9	2,222,608	2,222,608	121.5	2,143,027
Iowa	4,991,664				606,289	573,265	43.0	776,237	734,561	158.2	3,677,838
Kansas	4,994,975				1,369,331	1,369,331	125.9	1,170,415	1,169,415	144.6	2,456,229
Kentucky	3,726,271				404,188	404,188	69.9	1,935,466	1,854,501	220.4	1,467,582
Louisiana	2,890,429				33,366	33,348	7.8	1,436,098	1,051,963	148.0	1,805,118
Maine	1,676,799				678,316	678,316	32.5	539,948	539,948	23.3	458,535
Maryland	1,750,738							155,922	155,922	6.8	1,594,816
Massachusetts	3,262,885										3,262,885
Michigan	6,301,414	359,350	359,350	14.8	4,212,921	4,212,921	210.1	1,538,700	1,485,690	55.3	243,453
Minnesota	5,277,145	33,934	33,934	32.3	645,335	577,904	64.4	1,547,198	1,414,970	287.7	3,250,337
Mississippi	3,457,552				557,303	554,918	26.3	1,463,535	1,463,535	93.7	1,439,099
Missouri	6,012,652	4,869	4,869	8.6	1,161,329	1,161,329	243.4	2,120,067	2,120,067	436.9	2,726,387
Montana	3,676,416				915,096	915,096	46.0	1,661,587	1,661,587	113.2	1,099,733
Nebraska	3,870,739				848,451	848,451	81.0	1,457,904	1,425,453	141.3	1,596,834
Nevada	2,243,074				808,944	803,944	31.6	548,193	541,193	20.7	897,937
New Hampshire	945,225				167,186	165,277	6.2	100,215	99,978	3.0	679,970
New Jersey	3,129,805				448,969	448,969	6.7	1,249,006	1,249,006	6.2	1,431,830
New Mexico	2,871,397				558,106	558,106	53.0	443,483	443,483	39.0	1,869,808
New York	11,046,377				3,353,738	3,312,448	30.0	1,909,480	1,734,169	23.5	5,999,760
North Carolina	4,720,173				532,735	532,735	47.8	870,159	870,159	81.8	3,317,279
North Dakota	2,867,245	70,277	70,277	9.1	339,049	339,049	53.8	68,375	68,375	8.7	2,389,544
Ohio	7,670,815				877,612	877,612	7.5	1,253,000	1,253,000	14.4	5,540,203
Oklahoma	4,580,670				158,049	158,049	13.8	2,047,973	2,047,923	203.8	2,374,698
Oregon	3,038,642				819,430	819,430	25.2	1,101,639	1,077,374	84.0	1,141,838
Pennsylvania	9,347,797				156,356	156,356	.1	477,010	477,010	25.1	8,714,431
Rhode Island	989,208				39,916	39,916		171,277	171,277	7.2	778,016
South Carolina	2,702,012				296,459	296,459	25.2	145,383	145,383	17.3	2,260,171
South Dakota	2,976,454	79,686	79,686	30.1	428,618	428,618	125.2	314,898	314,898	77.8	2,153,251
Tennessee	4,192,460				338,156	338,156	18.2	559,491	559,491	20.7	3,294,814
Texas	11,989,350				2,511,258	2,402,296	218.4	3,766,930	3,671,784	336.2	5,915,271
Utah	2,067,154				365,218	348,599	29.0	467,154	397,770	41.9	1,320,784
Vermont	924,306				136,368	135,438	4.9	334,086	332,086	8.7	456,783
Virginia	3,652,667	29,453	29,453	14.9	534,678	534,678	391.4	766,459	766,459	269.4	2,322,077
Washington	3,026,161				1,072,862	1,017,886	38.5	1,005,009	927,269	71.2	1,081,005
West Virginia	2,231,412				577,056	577,056	30.8	204,515	194,118	7.3	1,460,237
Wisconsin	4,823,884				991,554	763,411	54.1	1,354,914	1,230,158	97.5	2,830,315
Wyoming	2,219,155				386,988	386,986	16.6	584,406	584,404	35.8	1,247,765
District of Columbia	949,496	95,395	95,395	.9	528,670	528,670	4.2	104,152	95,816	.9	229,615
Hawaii	926,033							196,335	195,477	1.7	730,556
TOTALS	195,000,000	672,964	672,964	110.7	34,177,152	33,559,204	2,535.1	53,210,051	51,586,202	4,247.3	109,181,630

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31, 1935.

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		
				Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise	
Alabama	4,034,617					832,793	832,793	10		1,877,056	1,877,056	21	1	1,324,768
Arizona	1,256,099					50,000	50,000	1						1,206,099
Arkansas	3,574,060					187,657	187,107	5		981,842	979,533	23		2,407,420
California	7,486,362					403,012	392,165	2		5,573,413	5,355,599	32		1,738,599
Colorado	2,631,567					292,247	291,952	8		649,815	628,815	8		1,710,800
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					644,152	644,152	6		481,323	481,323	4		1,702,409
Georgia	4,895,949													4,895,949
Idaho	1,674,479					378,051	355,875	6		303,886	281,540	5		1,037,064
Illinois	10,307,184					256,055	256,055	1		1,572,155	1,572,155	27		8,478,973
Indiana	5,111,096					1,112,975	1,112,975	3		1,545,566	1,545,565	14		2,452,556
Iowa	5,600,679					711,579	682,150	10		531,363	507,000	14		4,411,529
Kansas	5,246,258					78,694	78,694			1,187,871	1,187,871	19		3,979,693
Kentucky	3,672,387									2,603,670	2,050,829	19		1,621,558
Louisiana	3,213,467									1,190,482	931,000	11		2,282,467
Maine	1,426,861					79,488	79,013	1		290,180	290,180	4		1,057,668
Maryland	2,061,751									505,309	505,309	4		1,556,442
Massachusetts	4,210,833					393,711	393,711	2		363,286	363,286	1		3,453,836
Michigan	6,765,197					2,669,602	2,669,602	32		2,059,050	2,059,050	11		2,036,545
Minnesota	5,395,441					166,201	166,201	4		768,418	762,368	17	1	4,466,872
Mississippi	3,241,475					169,000	169,000	2		828,003	828,003	16		2,244,472
Missouri	6,142,153					203,387	203,387	2		637,243	637,243	8		5,301,523
Montana	2,722,327					591,772	591,772	10		1,091,070	1,091,070	23		1,039,485
Nebraska	3,556,441					271,757	271,757	15		1,492,712	1,492,712	40		1,791,972
Nevada	887,260					306,096	306,096	7		13,308	13,308			567,856
New Hampshire	822,484									140,766	140,766			681,718
New Jersey	3,983,826													3,983,826
New Mexico	1,725,286									571,042	557,215	9		1,168,071
New York	13,577,189					2,388,410	2,285,110	5		1,243,200	1,243,200	4		10,048,879
North Carolina	4,823,958					256,915	256,915	1		535,468	535,468	9		4,031,575
North Dakota	3,207,473					39,335	39,335	2		133,902	133,902	3		3,034,236
Ohio	8,439,897					126,598	126,598							8,313,298
Oklahoma	5,004,711					468,772	468,772	9		1,140,614	1,135,614	19		3,400,324
Oregon	2,334,204					502,229	501,102	3		293,978	293,344	2		1,539,758
Pennsylvania	11,483,613					219,670	203,527	5		418,400	373,900	11		10,906,186
Rhode Island	699,691					236,879	236,879							462,812
South Carolina	3,059,956					129,616	129,616	3		404,313	404,313	10		2,526,028
South Dakota	3,249,086					123,822	123,822	3		51,774	51,774	1		3,073,490
Tennessee	3,903,979					78,679	78,679	1		273,217	273,217	5		3,552,083
Texas	10,855,982					92,057	92,057	4		2,079,257	2,069,803	31		8,694,122
Utah	1,230,763					128,602	128,602	1		224,536	218,672	4		883,489
Vermont	729,857					307,976	306,617	3		167,609	167,609	4		255,631
Virginia	3,774,287					24,928	24,928	1		184,573	184,573	5		3,564,786
Washington	3,095,041					873,248	873,248	8		637,437	632,637	8		1,589,156
West Virginia	2,677,937													2,677,937
Wisconsin	5,022,683					577,061	520,134	7		875,751	834,582	6		3,667,967
Wyoming	1,360,841					55,366	55,365	2						1,305,476
District of Columbia	410,804									166,697	166,697	2		244,107
Hawaii	453,703									113,769	113,769	1		339,934
TOTALS	196,000,000					16,428,392	16,185,763	185		36,203,324	34,971,870	455	2	144,842,367

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933.

Report of the Chief of the Bureau of Public Roads, 1934.

DEPARTMENT BULLETINS

No. 136D . . Highway Bonds. 20 cents.

No. 347D . . Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.

No. 583D . . Reports on Experimental Convict Road Camp. Fulton County, Ga. 25 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

No. 191 . . . . Roadside Improvement. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF DECEMBER 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 12,979,571	$ 7,729,095	$ 2,089,448	682.8	$ 1,947,736	$ 582,710	$ 1,208,067	78.8		$ 397,253	13.0	$ 58,328	$ 565,074
Arizona	5,211,960	2,641,935	8,053,687	5,061,554	2,023,015	523.0	752,811	134,249	507,347	22.3		41,125	.5	16,057	70,448
Arkansas	6,748,335	3,428,049	9,644,999	6,421,999	2,260,117	530.4	1,116,949	164,431	949,864	71.9	$ 101,076	48,836	3.8	60,829	159,231
California	15,607,354	7,932,206	25,538,846	15,123,463	5,246,703	736.9	4,670,717	478,067	2,445,654	36.1		178,186	.7	5,824	61,663
Colorado	6,874,530	3,436,006	11,037,202	6,831,431	3,362,522	637.2	95,116		95,116	.6				43,099	28,368
Connecticut	2,865,740	1,454,868	4,215,522	2,859,411	341,105	69.3	359,166		343,645	3.7		58,859	.1	6,329	111,258
Delaware	1,819,088	923,395	2,644,057	1,818,961	775,652	129.3	42,012		42,012					126	105,731
Florida	5,231,834	2,661,343	8,129,789	5,182,694	1,756,426	275.0	709,012		627,057	32.3		178,968	1.7	49,140	98,892
Georgia	10,091,185	5,113,491	11,626,646	8,987,193	2,222,207	659.0	1,571,497	674,778	848,596	76.6	19,197	396,797	15.3	410,018	1,645,791
Idaho	4,436,249	2,277,486	6,221,202	4,395,105	1,450,600	488.8	657,458		656,209	8.5		56,567	2.8	91,144	114,111
Illinois	17,570,770	8,921,401	19,882,761	15,198,894	4,188,580	553.3	6,176,164	2,301,004	3,875,160	141.0		590,781	.5	70,873	266,879
Indiana	10,037,843	5,088,963	11,540,160	9,065,834	1,390,004	363.1	3,548,907	791,499	2,722,015	123.3	58,342	192,513	2.2	122,168	184,431
Iowa	10,055,660	5,118,361	15,304,534	9,883,155	4,630,491	1,212.2	428,888	170,404	230,700	12.9		1,000	2.2	2,101	256,170
Kansas	10,089,604	5,117,675	13,815,689	9,996,448	3,427,982	1,065.4	1,709,922	39,153	1,670,769	76.1	48,982	14,934	2.2	5,022	3,990
Kentucky	7,517,359	3,818,311	10,043,766	6,981,980	2,424,368	738.8	1,590,289	432,327	1,042,672	66.1	55,381	152,252	7.9	47,671	199,019
Louisiana	5,828,591	2,963,932	6,444,550	4,581,839	1,300,725	195.2	2,323,957	1,041,640	1,240,364	47.6	155,417	376,293	17.1	49,695	46,551
Maine	3,369,917	1,711,586	4,920,427	3,346,776	1,369,575	184.8	286,379		286,364	8.3				23,141	55,647
Maryland	3,564,527	1,810,058	4,277,424	2,778,170	600,931	113.6	1,168,010	716,844	438,995	32.8		162,409	4.9	69,512	607,723
Massachusetts	6,597,100	3,350,474	6,823,769	4,587,714	1,650,167	102.9	3,374,357	1,974,333	1,400,024	12.4				35,053	300,283
Michigan	12,736,227	6,452,568	17,524,881	12,550,953	4,042,853	654.8	2,523,502	117,227	2,348,297	114.1		30,825	.1	68,048	30,592
Minnesota	10,656,569	5,425,551	15,380,467	9,885,007	4,787,931	1,623.5	842,952	615,120	188,795	26.3	17,260	183,253	2.0	139,182	265,572
Mississippi	6,978,675	3,540,227	9,780,654	5,827,706	1,371,564	563.7	2,967,830	1,001,411	1,649,097	156.8	7,259	418,474	22.9	142,299	101,091
Missouri	12,180,306	6,173,740	14,550,617	10,867,588	2,745,086	1,321.5	4,425,522	1,185,562	3,127,490	129.2		240,598	.6	127,156	60,567
Montana	7,439,748	3,769,734	11,039,598	7,184,779	3,217,640	1,001.2	605,546	159,632	445,914	29.7				95,337	106,180
Nebraska	7,828,961	3,964,364	12,397,483	7,752,426	3,395,846	991.9	731,069	34,040	462,677	42.0				42,494	105,842
Nevada	4,545,917	2,302,356	6,641,677	4,502,450	1,984,444	735.6	359,003	26,150	296,747	21.7		1,650		17,317	19,514
New Hampshire	1,909,839	969,462	2,941,750	1,909,443	915,667	77:2	30,238		30,238	.5				396	23,558
New Jersey	6,346,039	3,220,879	6,960,279	6,014,766	588,610	75.6	2,636,867	175,941	2,143,993	12.6				155,332	488,276
New Mexico	5,792,935	2,941,700	8,184,716	5,634,473	2,370,444	747.6	439,280		439,280	19.7	114			158,348	131,976
New York	22,330,101	11,327,921	36,135,115	21,673,218	8,347,852	788.4	3,767,593	414,900	2,394,899	35.0	129,549	514,400	2.0	112,434	70,770
North Carolina	9,522,293	4,840,941	13,984,680	8,830,611	3,935,293	1,322.4	937,889	320,633	600,361	22.0	64,450	212,350	4.3	306,599	92,937
North Dakota	5,804,448	2,938,967	7,321,364	5,518,203	1,157,590	1,949.5	748,802	130,778	559,429	112.3	67,289	492,657	60.7	88,178	729,291
Ohio	15,484,592	7,865,012	22,259,969	15,279,029	5,375,622	743.2	2,279,516	161,431	1,920,916	32.4		335,658	13.3	44,132	232,816
Oklahoma	9,216,798	4,685,180	12,635,607	8,874,279	2,931,136	753.2	1,587,592	323,398	1,262,459	49.8		178,597	1.1	19,121	312,988
Oregon	6,106,896	3,097,814	9,380,531	5,897,458	2,673,854	461.4	435,492	99,557	264,264	4.0				109,880	159,696
Pennsylvania	18,891,004	9,590,788	27,103,393	17,876,517	8,021,122	993.9	1,741,489	763,474	891,968	85.7	5,126	307,671	2.1	245,886	370,026
Rhode Island	1,998,708	1,014,572	2,959,600	1,994,413	853,971	88.0	138,587		137,102	1.1		880		4,295	22,619
South Carolina	5,459,165	2,770,954	5,929,981	4,953,067	859,933	458.3	1,861,400	367,719	1,455,359	159.9	15,740	53,304	.3	122,639	402,358
South Dakota	6,011,479	3,047,643	8,494,583	5,777,253	2,168,397	1,463.3	445,595	17,045	428,550	57.6	62,646	371,065	31.6	154,534	79,632
Tennessee	8,492,619	4,302,991	11,690,366	8,180,321	2,641,483	453.1	1,491,399	225,333	1,169,665	30.0	83,206	185,008	2.8	3,760	306,835
Texas	24,244,024	12,291,253	32,487,212	23,386,605	7,595,530	2,598.9	5,494,572	821,696	4,425,689	176.7	1,537	148,932	16.7	34,187	121,102
Utah	4,194,708	2,132,691	6,583,011	4,000,360	1,807,147	579.6	613,128	167,060	322,191	11.4		1,000		27,288	2,353
Vermont	1,867,573	948,007	3,035,765	1,846,336	849,229	137.6	109,059	3,922	90,873	2.4		2,713		17,315	5,192
Virginia	7,416,757	3,765,387	10,976,790	7,161,309	2,910,118	555.3	746,004	131,402	602,187	62.1	42,221	45,681	.8	81,825	207,401
Washington	6,115,867	3,106,412	8,843,000	6,101,000	2,527,319	299.5	524,373		518,276	3.3		4,691		14,867	56,125
West Virginia	4,474,234	2,280,335	5,264,100	4,167,184	928,672	182.6	1,259,030	268,494	938,583	35.8	5,987	3,000	.1	32,569	410,081
Wisconsin	9,724,881	4,941,837	14,867,069	9,639,754	4,340,950	605.0	584,701	7,300	534,958	15.4		51,605		77,827	14,325
Wyoming	4,501,327	2,287,712	6,564,177	4,441,334	1,933,314	987.8	359,722	46,705	286,281	49.5		60,239		13,288	7,879
District of Columbia	1,918,469	973,842	2,530,169	1,918,173	611,996	18.8	75,066		75,066	1.4		250,876	2.2	296	35,904
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,407,934	700,733	534,135	19.0	39,709	169,484	2.0		246,158
TOTALS	394,000,000	200,000,000	549,098,153	371,608,451	131,601,231	32,525.6	74,700,099	17,788,102	51,176,469	2,370.7	980,488	7,111,384	240.5	3,622,959	10,110,916

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BUREAU OF PUBLIC ROADS

VOL. 16, NO. 12

FEBRUARY 1936

PERFORMING THE SOIL COMPRESSION TEST

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Issued by the
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Volume 16, No. 12 February 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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A METHOD OF PREDICTING SETTLEMENT OF FILLS PLACED ON MUCK BEDS

DATA FROM COMPRESSION TEST USED IN ESTIMATING RATE AND AMOUNT OF SETTLEMENT

Reported by **F. A. ROBESON**, Junior Highway Engineer, Division of Tests[1]

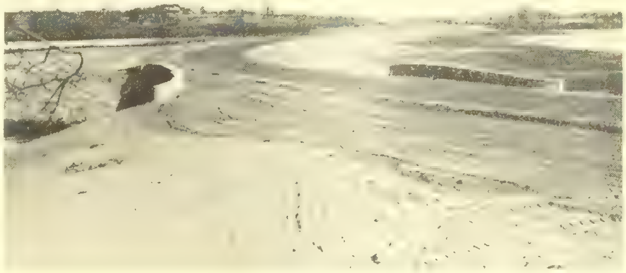
SETTLEMENT of fills on muck soils is one of the oldest problems with which engineers have had to deal. Until recently the only guides in predicting settlement were records of observed settlements of fills thought to have been placed under conditions similar to those affecting the fill for which estimates were being made. Only very limited records are available, and for most of the older fills that have settled the amount of settlement cannot be ascertained. In railroad valuation work in the swamps in the Southeastern States there was considerable discussion as to the amount to be allowed for earthwork that could not be measured readily because of fill settlement.

Many fills must be placed on muck beds of sedimentary origin that are below the normal water level. Samples of the muck may contain considerably more moisture, by weight, than solid material. The beds range from a few feet up to 30 feet or more in thickness and generally rest upon sandy or gravelly material of relatively stable character.

It has been observed that when fill material is placed on muck with distinctly fluid characteristics, the weight of the fill causes muck to flow outward and upward at the sides of the fill. Mounds of muck are formed that tend to produce a condition of equilibrium. At the same time the weight of the fill on the muck layer forces contained water to escape by seepage through the muck and the layers of material above and below it. If these layers are porous, final settlement will be attained more quickly than when the escaping water encounters considerable resistance. Seepage of water and fill settlement continue until a condition of equiibrium between muck stability and weight of fill is reached—generally a matter of several years.

Knowledge of these characteristics has been used to mprove methods of fill construction. Fills have been constructed by first placing a windrow of material along each edge of the proposed fill so as to trap the top layer of fluid muck and partly prevent the escape of muck o the sides. Fills are also placed in layers so as to allow time for the muck to consolidate under moderate oad rather than subject it immediately to a heavy pressure that forces the flow of large quantities of muck rom beneath the fill. When possible, granular material s used for the lower portion of the fill to facilitate scape of water pressed from the muck by the weight f the fill.

No satisfactory method for determining fill settlement in advance of construction has been developed. Studies made in connection with the construction of a ydraulic fill on muck soil at Four Mile Run on the Mount Vernon Memorial Highway have resulted in the evelopment of methods of estimating settlements ased on tests of undisturbed muck samples and data n the weight of the fill and depth of the muck deposit.



FILL AT FOUR MILE RUN IMMEDIATELY AFTER CONSTRUCTION. PICTURE TAKEN AT LOW TIDE.

Comparison has been made between the actual performance of soft undersoils under the particular conditions existing at Four Mile Run with the performance suggested by laboratory and mathematical analysis. Settlement of the fill and the moisture contents of the soil beneath the fill, as computed from the results of tests on samples of undisturbed undersoil, are compared in the following pages with actual settlements measured in the field and with moisture contents of samples taken from beneath the fill.

In constructing the fill, gravel was pumped from the river bed by the hydraulic method and placed on a layer of soft river-bottom sediment, 10 to 30 feet thick, resting on a firm sand foundation.

The general plan of the improvement, the longitudinal profile of the fill material, and the manner in which it was deposited are shown in figure 1. Figure 2 shows cross sections of the fill.

SAMPLE BORINGS TESTED IN THE LABORATORY

Because of slides and settlement during construction, the quantity of fill material placed was considerably greater than was originally estimated to be needed. Six months after completion of the fill, borings were made through the fill material and muck undersoil as part of an investigation of the factors responsible for the necessity of using excess fill material.

The borings were of two kinds: Probe borings, marked "P", in figure 1, that disclosed only the general character of the material penetrated; and sample borings, marked "S", that furnished samples of the soft undersoil in the undisturbed natural state in addition to information on the general character of the material penetrated.

Data obtained from laboratory tests made it possible to estimate (1) the ultimate settlement of the fill; (2) the settlement that may be attained during any time interval after construction; (3) total settlement after any period of time due both to lateral flow of the soft

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[1] This report supplements the report entitled "A Study of Hydraulic Fill Settle- ent", by Henry Aaron, PUBLIC ROADS, vol. 15, no. 1, March 1934.

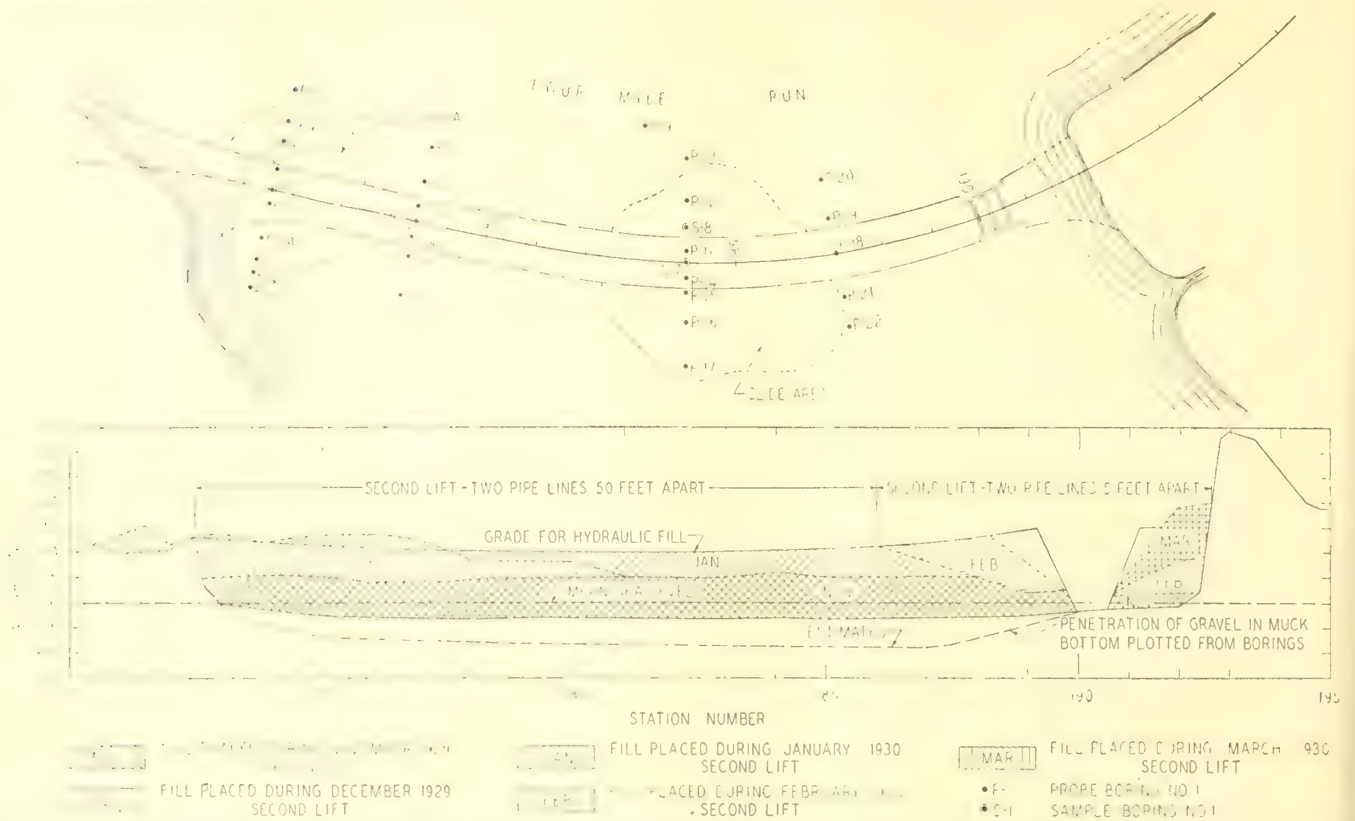
FOUR MILE RUN
S-8
SECOND LIFT - TWO PIPE LINES 50 FEET APART
GRADE FOR HYDRAULIC FILL
JAN
FEB
MAR
PENETRATION OF GRAVEL IN MUCK
BOTTOM PLOTTED FROM BORINGS
190
195
STATION NUMBER
FILL PLACED DURING DECEMBER 1929 SECOND LIFT
FILL PLACED DURING JANUARY 1930 SECOND LIFT
SECOND LIFT
FILL PLACED DURING MARCH 1930 SECOND LIFT
PROBE BORING NO 1
SAMPLE BORING NO 1

Figure 1.—Location of Borings and Progress in Constructing Hydraulic Fill at Four Mile Run, Mount Vernon Memorial Highway.

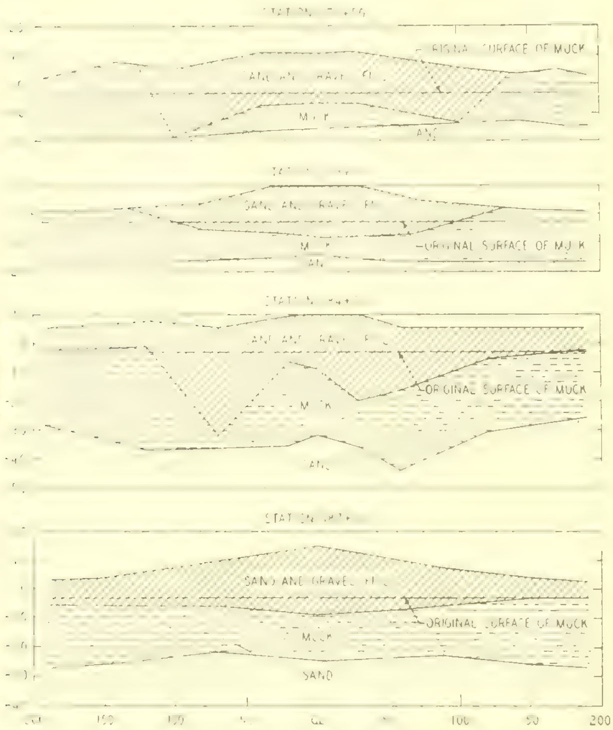

Figure 2.—Cross Sections of Fill as Indicated by Borings.

undersoil during the construction and to subsequent consolidation of the undersoil; and (4) the degree of consolidation as indicated by tbe moisture content, at any given depth in the undersoil at any time subsequent to construction of the fill.

The laboratory examinations included determinations of the physical characteristics of the constituents of the undersoil by the plasticity and shrinkage tests, and of the load-deformation relations of the undersoil in both undisturbed and remolded states by means of the Terzaghi compression test.

In all, 10 core samples were tested for natural moisture contents and plasticity and shrinkage constants. The results are shown in table 1. It should be first noted (table 1) that the agreement of osberved natural moisture contents with the liquid limits is generally good, further substantiating the findings of Dr. Terzaghi.[2]

Table 1.—*Results of laboratory tests on cores*

Boring no.	Core no.	Moisture content, natural state	Liquid limit	Plasticity index	Shrinkag limit
S-2	2	76	77	38	
S-4	1	108	103	49	
S-5	[1] 3	120	128	66	
	[1] 4	107	131	64	
S-6	5	125	132	69	
S-7	[1] 8	64	89	48	
	9	105	96	47	
	10	116	112	61	
S-9	6	79	62	30	
	[1] 7	117	79	36	

[1] These cores were nonuniform and were not suitable for compression tests. Therefore, they are not considered in the analysis of the test data.

The plasticity indexes and shrinkage limits are plotted against liquid limits in figures 3A and 3B, respectively. Soil classification criteria [3] indicate that

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[2] See Simplified Soil Tests for Subgrades and Their Physical Significance, by D Charles Terzaghi, Public Roads, vol. 7, no. 8, October 1926.

[3] See Soil Constants, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Wil pt. 3, Public Roads, vol. 12, no. 5, July 1931.

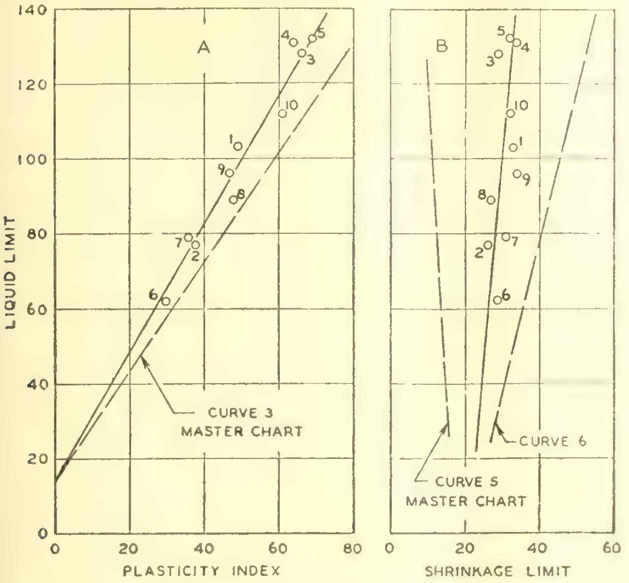

FIGURE 3.—PHYSICAL CHARACTERISTICS OF MUCK SAMPLE.

these samples have the properties of the A–8 subgrade group with less plasticity and more elasticity than the highly flocculated clays of the A–7 group.

Whereas purely inert fine clay particles could furnish the plasticity indicated by curve 3, such particles would produce shrinkage limits indicated by curve 5. Plastic colloidal clays with decomposed organic matter, however, containing elastic materials such as fibrous organic matter or diatoms, would have the constants shown in figures 3A and 3B.

The fact that the plotted plasticity indexes and shrinkage limits have approximately a straight-line relation to the liquid limits indicates variation in sand content only. Considerable change in character of fine material would cause corresponding variations from the straight-line relation.

TERZAGHI COMPRESSION DEVICE DESCRIBED

The essential features of the Terzaghi compression device[4] are illustrated in figure 4. A soil sample is placed between two porous stones, the upper one forming the base of a piston which loads the sample. Water drains freely from both faces of the sample under pressure and passes through the stones, escaping from overflow orifices *a* and *b*. This egress of water educes the thickness of the sample which cannot be leformed laterally. The compression of the sample s measured by very sensitive micrometer dials.

Loads are applied in successive increments, each oad being about double the preceding one, the maxinum being equal to or greater than the pressure on he stratum from which the sample was taken. The lensity of the sample at various stages of the loading s indicated by either the moisture content or the atio of pores to solids and is termed the voids ratio f the soil mass.[5] Each load increment is allowed to

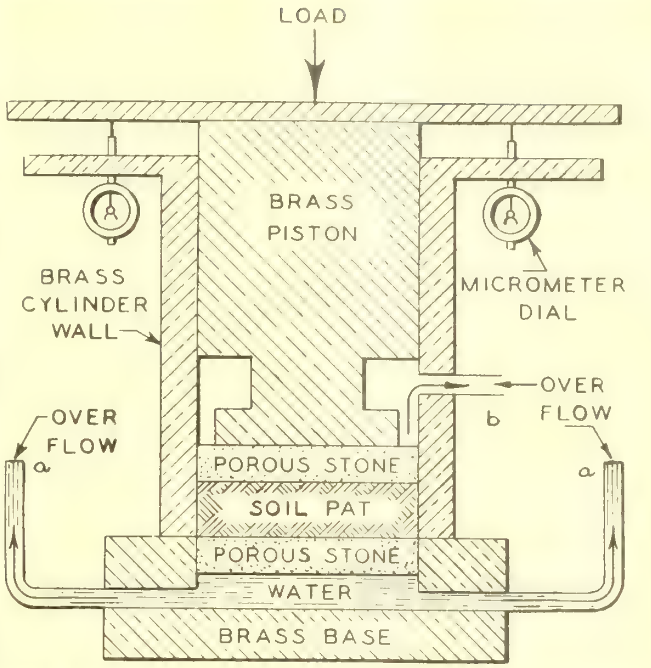

FIGURE 4.—ESSENTIAL ELEMENTS OF TERZAGHI COMPRESSION DEVICE.

act until further consolidation of the sample under that load is immeasurable. Thus the voids ratio at any stage of loading indicates the maximum density likely to be produced by the corresponding load.

In the determination of the load-deformation characteristics of the material in the natural state the samples were transferred from the hermetically sealed containers in which the soil was placed at the time of sampling to the testing apparatus with as little disturbance as possible.

A disk of undisturbed material was carefully cut from each core, trimmed to the correct diameter with a piano wire saw, and carefully placed in the testing apparatus. This transfer was made in a damp closet to prevent loss of moisture from the sample.

TEST FURNISHES LOAD-COMPRESSION, LOAD-EXPANSION, AND TIME-COMPRESSION DATA

In the test to determine properties of the disturbed material, a sample of soil from each core was first thoroughly manipulated by means of a spatula with no addition of water and then carefully placed in the testing apparatus.

The compression test furnishes three relations as follows:

1. Load-compression, or relation between voids ratio and increasing load.
2. Load-expansion, or relation between voids ratio and decreasing load.
3. Time-compression, or relation between percentage of consolidation and time.

Curves presenting these relations are shown in figure 5.[6] They were based on tests of a remolded sample from core no. 5, boring S–6, located 80 feet to the left of the centerline, station 178+50.

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[4] See Subgrade Soil Constants, Their Significance, and Their Application in Prac-ce, by C. A. Hogentogler, A. M. Wintermyer, and E. A. Willis, PUBLIC ROADS, ol. 12, no. 4, June 1931; Principles of Final Soil Classification, by Dr. Charles Ter-ghi, PUBLIC ROADS, vol. 8, no. 3, May 1927; Soil Mechanics Research, by Dr. Glen-on Gilboy, Proceedings American Society of Civil Engineers, vol. 57, no. 8, October 31; and The Structure of Clay and Its Importance in Foundation Engineering, by rthur Casagrande, Journal of the Boston Society of Civil Engineers, vol. 19, no. 4, pril 1932.

[5] Voids ratio, e, equals moisture content, w, multiplied by the specific gravity of e soil solids, G_s.

[6] In the compression test the loads are expressed in kgs per sq. cm. One kg per sq. cm equals 2,048.5 pounds or approximately 1 ton per sq. ft. For convenience in presenting the analysis of the compression test data, therefore, kgs per sq. cm and tons per sq. ft. are used more or less interchangeably.

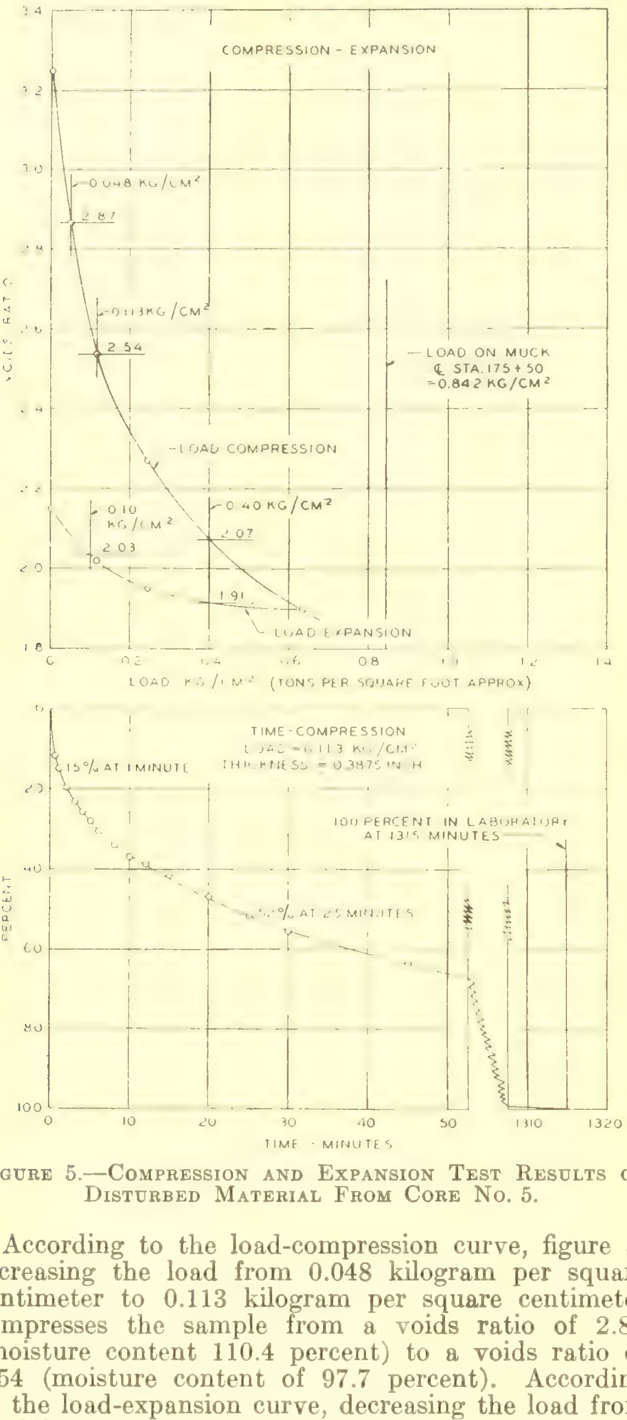

Figure 5.—Compression and Expansion Test Results on Disturbed Material From Core No. 5.

According to the load-compression curve, figure 5, increasing the load from 0.048 kilogram per square centimeter to 0.113 kilogram per square centimeter compresses the sample from a voids ratio of 2.87 (moisture content 110.4 percent) to a voids ratio of 2.54 (moisture content of 97.7 percent). According to the load-expansion curve, decreasing the load from 0.4 kilogram per square centimeter to 0.1 kilogram per square centimeter increases the voids ratio from 1.91 (moisture content 73.5) to 2.03 (moisture content 78.1). According to the time compression curve, 52 percent of the above compression occurs in 25 minutes. Thus the voids ratio of the sample 25 minutes after the load was increased from 0.048 kilogram per square centimeter to 0.113 kilogram per square centimeter equals $2.87-\frac{52}{100}\times(2.87-2.54)$ or 2.70.

The relative periods of load application producing equal percentages of compression in the soil strata and in their representative laboratory samples depend upon the relative distances that water must travel to escape. If the field stratum is free to drain from both upper and lower surfaces (as when between two permeable layers) the ratio of the rate of compression of the stratum to that of the laboratory sample representing it is equal to the ratio of the squares of their respective thicknesses. If, however, the stratum can drain from only one surface then the ratio of the two rates of compression is equal to four times the ratio of the squares of their respective thicknesses. This will be developed later.

To illustrate, assume that a load of 0.048 kilogram per square centimeter that has acted for a long time on a muck layer 10 feet thick is increased to 0.113 kilogram per square centimeter. Considering that the curves, figure 5, represent the laboratory test on a sample of the field layer, the voids ratio of the field layer will decrease from 2.87 to 2.54 ultimately under this new load. This represents a decrease in thickness of

$$\frac{2.87-2.54}{1+2.87}\times 100$$

or 8.5 percent of the total. Consequently the ultimate thickness equals $(1.00-0.085)\times 10$ or 9.15 feet, a compression of 0.85 foot. If the laboratory sample is 0.4 inch thick at a voids ratio of 2.87, the ratio of the time to effect consolidation of the stratum to the time to produce the same condition in the sample is $\frac{(10\times 12)^2}{(0.4)^2}$ or 90,000 to 1. In other words an effect is produced on the laboratory sample in 1 minute equivalent to that produced on the stratum in the field in 90,000 minutes, or about 60 days. The time-compression curve, figure 5, shows that 15 percent of the consolidation occurs in that time. Consequently the thickness of the muck layer 60 days after the increase in load was $10-\left(\frac{15}{100}\times 0.85\right)$ or about 9.9 feet.

COMPUTED SETTLEMENTS AGREE CLOSELY WITH ACTUAL SETTLEMENTS

For reasons noted in table 1, four of the core samples were considered as being unsuited for use in the settlement analysis. Compression-test data for the remaining six samples are shown in figure 6. This figure shows the profile of each boring and the compression characteristics of the materials in both the natural, or undisturbed state, and the remolded, or disturbed state.

It is noted that in every instance equal loads produced greater compression of the disturbed material than of the undisturbed material. This action, well recognized by foundation engineers, is caused by a breaking down of the soil structure by mixing.

Tables 2 and 3 and figure 7 show computed moisture contents and settlements based on the characteristics of the materials and these values are compared with actual settlements as measured and moisture contents as determined by drying samples.

Table 2.—*Computed and measured moisture contents*

Material from core	Moisture content	
	Computed	Measured
	Percent	*Percent*
1	123	108
2	60	76
5	123	125
6	77	79
9	86	105
10	109	116

TABLE 3.—*Estimated settlements caused by lateral flow that occurred during construction and observed*[1] *and computed settlements that occurred after construction*

	40 feet left of 175+50			At 175+50			30 feet right of 175+50			30 feet left of 178+50			At 178+50		
	Computed		Measured	Computed		Measured	Computed		Measured	Computed		Measured	Computed		Measured
	Core 2	Core 10		Core 2	Core 10		Core 2	Core 10		Core 2	Core 10		Core 2	Core 10	
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1 month	0.2	0.9	0.3	0.3	0.9	0.4	0.3	1.0	0.3	0.3	0.9	0.3	0.2	0.9	0.2
6 months	.6	2.2	.8	.6	2.2	.9	.6	2.2	.7	.6	2.2	.9	.5	1.8	.7
12 months	.7	2.8	1.0	.8	2.8	1.1	.8	2.8	.9	.8	2.8	1.1	.6	2.1	.9
20 months	.9	3.1		.9	3.1	1.4	.9	3.1		.9	3.1		.7	2.2	1.1
36 months	1.0	3.4		1.0	3.3	1.6	1.0	3.3		1.0	3.3		.8	2.3	1.3
Ultimate	1.6	4.0		1.7	3.9		1.6	3.8		1.6	3.9		1.0	2.6	
Lateral flow	3.5	1.9		3.2	1.6		3.1	1.5		2.4	.8		4.4	3.1	

	30 feet right of 178+50			20 feet left of 184+00			At 184+00			30 feet right of 184+00			At 187+00		
	Computed		Measured	Computed		Measured	Computed		Measured	Computed		Measured	Computed		Measured
	Core 2	Core 10		Core 2	Core 10		Core 2	Core 10		Core 2	Core 10		Core 2	Core 10	
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
1 month	0.2	0.9	0.3	0.2	0.4	0.2	0.2	0.4	0.3	0.1	0.4	0.4	0.2	0.6	0.5
6 months	.5	2.1	.8	.4	1.4	.8	.4	1.5	.9	.3	1.4	1.0	.5	2.0	1.4
12 months	.7	2.6	1.1	.6	2.3	1.4	.6	2.2	1.5	.5	2.0	1.6	.7	2.8	1.9
20 months	.8	2.9		.7	2.9		.7	2.9	1.9	.6	2.5		.9	3.4	2.4
36 months	.9	3.1		1.0	3.8		1.0	3.7	2.9	.7	3.1		1.2	4.2	3.1
Ultimate	1.5	3.6		3.4	8.2		2.8	6.8		1.7	4.7		2.6	6.0	
Lateral flow	3.6	2.0		2.9	1.9		4.9	3.8		16.7	15.6		5.3	3.8	

[1] Measurements on centerline locations continued after construction of pavement.

Data for 10 locations are given in figure 7. The shaded bands show the range of possible settlements as computed from data obtained by tests of core 2 material representing the stiffest muck and core 10 material representing the softest muck in the deposit. Choice of these two was made on the basis of the load-compression and time-compression characteristics of the six cores investigated.

Table 3 contains the settlement data from which figure 7 was plotted. It will be noted that for the four centerline locations the measured settlements are recorded for 36 months. This is because only the levels at the centerline location were continued after the construction of the paved roadway.

According to table 3 the losses in thickness resulting from lateral flow were, in many cases, much greater than the computed ultimate settlements. This indicates that these losses are likely to be proportionately greater than those resulting from settlement in fills over similar muck beds.

All of the observed settlements are within the range of the computed maximum and minimum settlements. Since the computed maximum settlements were always greater than the observed settlements, errors in the computed settlements are on the conservative side. The differences between observed and computed settlements and moisture contents are not due to faulty theory but result from certain assumptions used in the computations in the absence of information that could only be obtained with considerable difficulty.

ASSUMPTION AS TO CHARACTER OF MUCK MUST BE MADE WITH CARE

In the foregoing computations there were two assumptions that are most likely to be at fault. They are that the muck was uniform throughout the depth of the deposit at any location and that moisture was free to flow from both top and bottom of the compressed layer. Actually, boring S–7, from which three cores were taken, indicated mucks having liquid limits varying from 89 to 112, and boring S–9, from which two cores were taken, had a liquid limit range of 62 to 79.

Visual inspection of the cores showed that the sand content varied considerably within the depth of the cores themselves. This was positive evidence of nonuniformity of the soil within a 1-foot range.

As previously stated, the rate of settlement is but one-fourth as rapid when the water is free to flow from only one face instead of both faces of the soil layer. The intrusion of stiff soil laminations into a more permeable layer tends to interfere with the free flow of water and to retard the process of settlement. In a layer of stiff muck, thin deposits of soft muck tend to increase the rate of settlement. Therefore, assuming free flow through both top and bottom of the layer, settlements computed on the basis of the stiff muck are apt to be less than those observed, whereas settlements computed on the basis of the soft muck will undoubtedly be larger than those actually occurring.

This is illustrated in figure 8. All the information in the case of boring S–2 indicates that muck represented by core 2 dominates. As is shown by figure 8, the observed settlement is slightly greater than that computed on the basis of core 2 material.

All the information in the case of boring S–7 indicates that core 10 material dominates but the deposit contains layers of core 9 material. As would be expected, therefore, the observed settlement (full-line curve, fig. 8) lies between settlements computed on the basis of the materials from cores 9 and 10, on the assumption of free flow in both directions.

The observed settlements, however, are greater than those computed on the basis of core 10 material when free to discharge water from one face only. It is

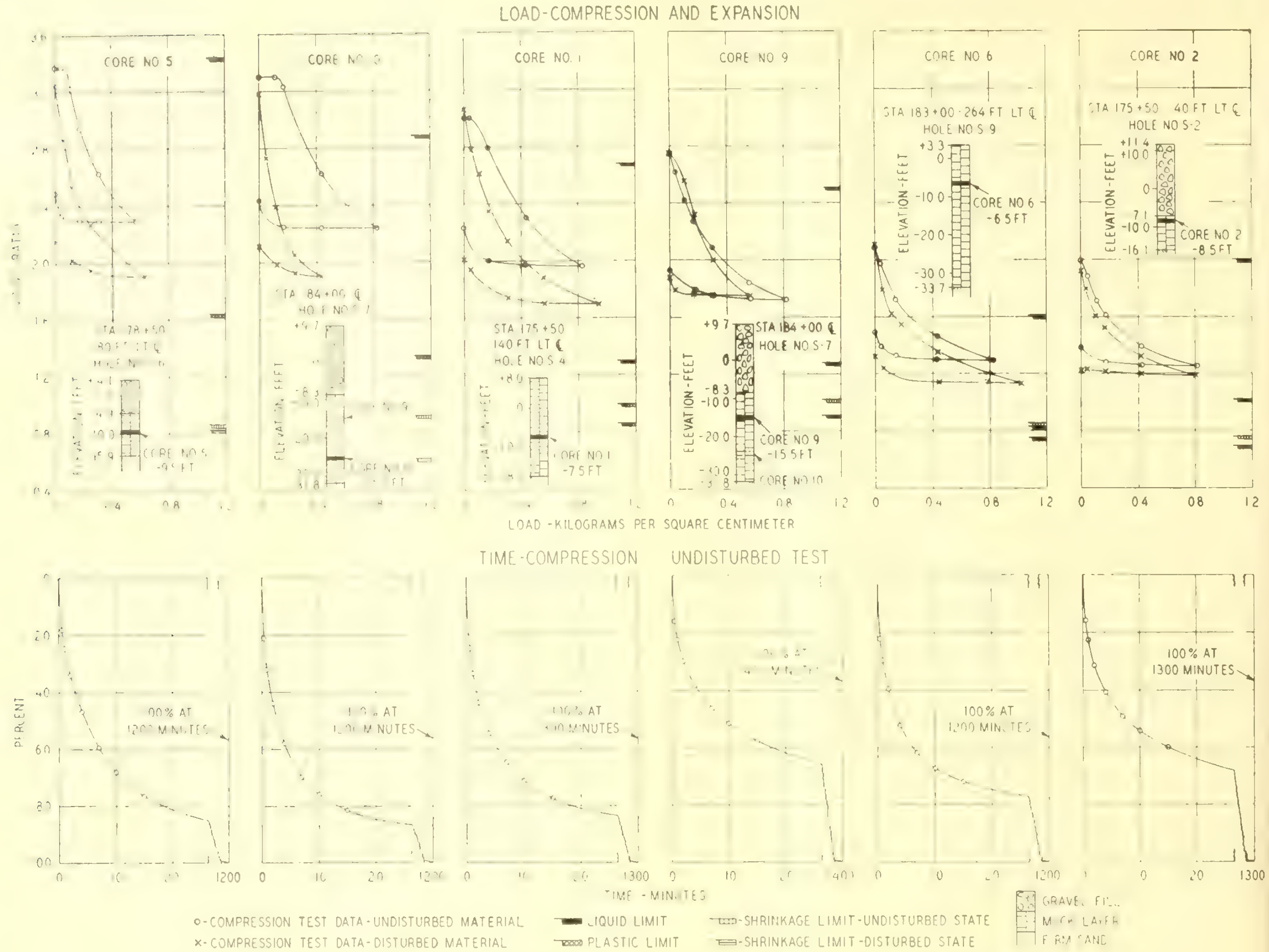

FIGURE 6.—ESSENTIAL DATA ON CORE MATERIALS USED IN THE ANALYSES.

indicated that the laminations of core 9 material retard the flow of water through the core 10 material but do not completely seal off the flow from either face.

In this connection it can be noted in table 2 that there is a much better agreement between the computed and measured moisture contents of core 10 material than of core 9 material.

RESULTS OF INVESTIGATION SUMMARIZED

The study of conditions at Four Mile Run has resulted in the following conclusions:

1. The muck at Four Mile Run belongs to the truly unstable group designated as A–8. It is distinguished by high water capacity, relatively low plasticity, and high elasticity.

2. The wide range of observed moisture contents—76 to 125 percent of weight of dried soil—is caused by differences in the compressibility of the soil at different locations in the deposit.

3. Differences in the compressibility of the soil result from variations in the clay content more than from variation in the activity of the clay content.

4. The agreement between the computed and the observed settlements indicates that the settlements of soil layers in place follow the same laws used in the analysis of data obtained by laboratory compression tests. The lack of agreement between observed and computed settlements is caused by lack of uniformity of the soil deposits. The theory regarding the relative amounts and rates of consolidation of laboratory samples and field strata seems entirely sound.

5. The agreement between the computed and the determined moisture contents, although not exact, is close enough to emphasize that wide variation in observed moisture contents at different locations in a soil deposit are not the result of haphazard circumstances, but instead are the demonstration of fairly well understood physical laws that control the consolidation of sediments.

6. Close agreement between observed and computed settlements is due largely to the uniformity of the soil deposit investigated. The greater the uniformity the more accurately will the computed settlements indicate the actual settlements.

7. Lateral flow is a major cause for concern in placing fills on muck deposits of the type described. Construction methods that will lessen or prevent lateral flow are highly desirable and contribute to greater accuracy in forecasting probable settlements.[7]

TEST PROCEDURE AND ANALYSIS OF DATA DISCUSSED

The foregoing discussion has been prepared to illustrate in a general way how problems of fill settlement

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[7] See A Study of Hydraulic Fill Settlement, by Henry Aaron, PUBLIC ROADS, vol. 15, no. 1, March 1934.

TABLE 4.—*Data furnished by the combined compression and permeability tests on Four Mile Run core sample no. 5 remolded at natural moisture content* [1]

A—GENERAL DATA

Depth of soil chamber, start of test	0.4254 inches.
Cross-sectional area of compressibility chamber, A	38.5 sq. cms.
Lever ratio (loads placed directly on piston)	1:1.
Cross-sectional area of permeameter tube, a	0.10 sq. cms.
Specific gravity of soil solids, G_s	2.60.
Initial moisture content	123.0 percent.
Weight of water at end of test	21.05 grams.
Weight of dry soil at end of test	25.46 grams.
Moisture content at end of test	82.7 percent.

B—LOAD-COMPRESSION AND TIME-COMPRESSION DATA

Date	Hour	Elapsed time (t)	Load		Micrometer reading			Consolidation	
			Increment	Total unit pressure (p)	Left	Right	Average		
	p. m.	*Minutes*		*Kg per sq. cm*	*Inches* $\times 10^{-4}$	*Inches* $\times 10^{-4}$	*Inches* $\times 10^{-4}$	*Inches* $\times 10^{-4}$	*Per cent*
Aug. 28	2:20		None	None	0	0	0		
Do	2:20	0	First	0.048	0	0			
Aug. 29	1:30	1,390	do	.048	379	379	379		
Do	3:30	0	Second	.113	379	379	379	0	0
Do	3:30.5	.5	do	.113	418	416	417	38	11.6
Do	3:31	1	do	.113	429	427	428	49	15.0
Do	3:32	2	do	.113	444	443	443.5	64.5	19.7
Do	3:33	3	do	.113	455	453	454.5	75.5	23.1
Do	3:34	4	do	.113	464	463	463.5	84.5	25.8
Do	3:35	5	do	.113	470	472	471	92	28.1
Do	3:36	6	do	.113	478	480	479	100	30.5
Do	3:38	8	do	.113	489	491	490	111	33.9
Do	3:40	10	do	.113	499	501	500	121	37.0
Do	3:42	12	do	.113	504	508	506	127	38.8
Do	3:45	15	do	.113	516	513	514.5	135.5	41.4
Do	3:50	20	do	.113	530	535	532.5	153.5	46.9
Do	3:55	25	do	.113	547	550	548.5	169.5	51.8
Do	4:00	30	do	.113	559	562	560.5	181.5	55.4
Do	4:15	45	do	.113	586	588	587	208	63.5
Aug. 30	*a. m.* 9:10	1,060	do	.113	689	697	693	314	95.9
Do	*p. m.* 1:25	1,315	do	.113	700	713	706.5	[2]327.5	100.0
Do	3:30	0	Third	.244	700	713			
Sept. 1	2:30	2,820	do	.244	968	988	978		
Do	4:35	0	Fourth	.634	968	988			
Sept. 2	1:10	1,235	do	.634	1,329	1,365	1,347		

C—LOAD-EXPANSION DATA

Sept. 2	*p. m.* 3:25		Third	0.244	1,329	1,365			
Sept. 3	*a. m.* 11:45		do	.244	1,284	1,314	1,299		
Do	11:45		Second	.113	1,284	1,314			
Sept. 4	9:10		do	.113	1,218	1,250	1,234		
Do	9:10		First	.048	1,218	1,250			
Sept. 5	9:30		do	.048	1,114	1,144	1,129		

D—PERMEABILITY TEST DATA [3]

Date	Temperature (T)	Elapsed time	Permeameter tube reading	Head of water [4]	
				h_1	h_2
	°*C*	*Minutes*		*Cm*	*Cm*
Aug. 30	27.2	0	0.11	24.14	
		60	.26		22.89
Do	27.2	0	.11	24.14	
		60	.25		22.99
Average				24.14	22.94

[1] Abbreviated to include only one set of time-compression readings and one permeability test.

[2] Total consolidation under second load increment.

[3] For test performed at end of second load increment.

[4] Values corrected for capillary rise in permeameter tube.

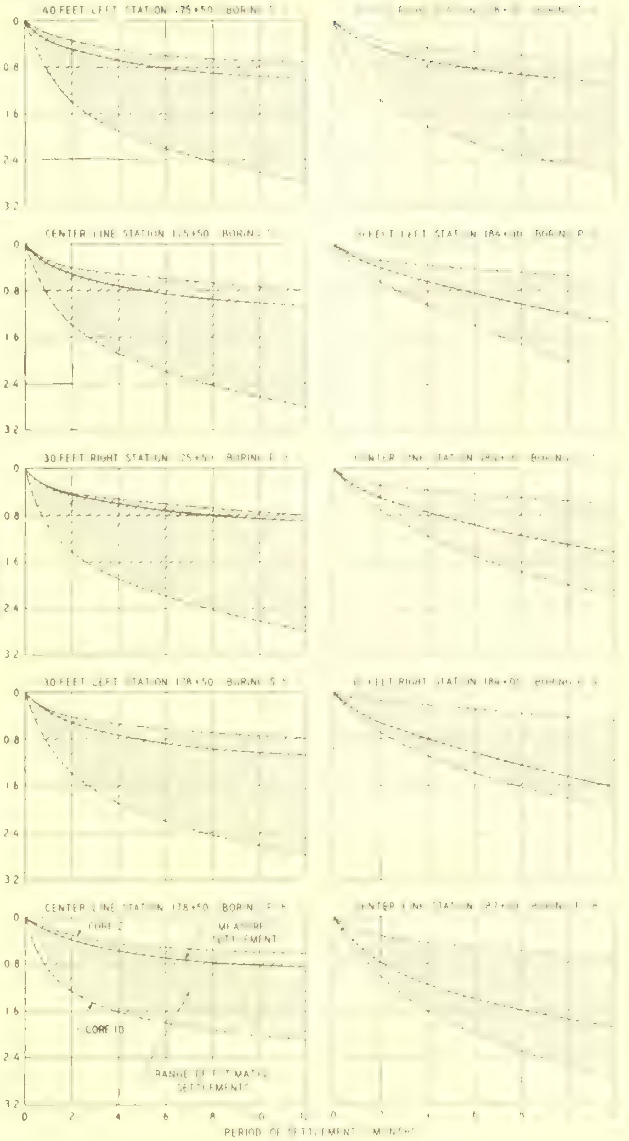

FIGURE 7.—COMPARISON OF MEASURED AND ESTIMATED FILL SETTLEMENTS.

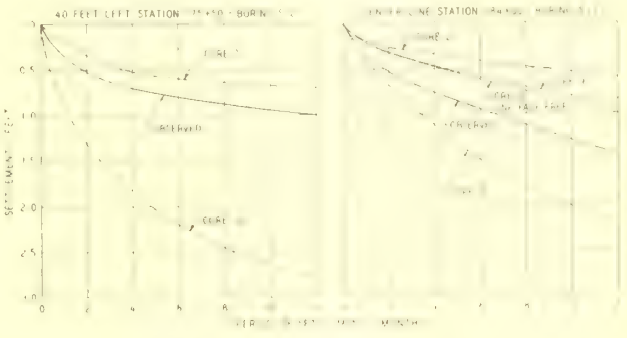

FIGURE 8.—COMPUTED AND MEASURED SETTLEMENTS OF RELATIVELY STIFF AND SOFT MUCKS.

may be attacked. The soil specialist dealing with such problems will desire a more detailed account of the procedure involved. In the following pages an effort is made to give such information.

The small number of laboratories equipped to make the compression test follow a more or less standard procedure but no detailed description of the procedure is known to have been published. It is not the primary purpose of this report to give the procedure, but the condensed data with computations and explanations presented in table 4 will enable one to perform the test.

Table 4 shows the data from which the curves of figure 5 were drawn. It also shows the results of one permeability test. The permeability test is not used in the subsequent analyses and is presented in table 4 only because it is usually performed in conjunction with the compression test. In performing the permeability test a permeameter tube is attached to one of the orifices *a*, figure 4, with the other orifice *a* closed, permitting the flow of water through the soil under known heads, the water escaping through orifice *b*.

Table 4–A presents such general information concerning the sample and apparatus as is necessary in computing results. If routine tests are not contemplated, it is necessary to determine the specific gravity by a separate test.

Table 4–B presents data taken during the application of load to the sample and includes a complete set of time-displacement readings. At the start of the test a pin holds the piston in a fixed position in the cylinder. Dial-type micrometers are attached and set at a suitable initial reading, which was zero in this case.

Table 4–C presents the load-expansion data. The loads are usually removed in reverse order to that used in the load-compression portion of the test.

Table 4–D gives the permeability test data. This test is usually run after the application of each load increment when the soil has reached a constant voids ratio for that load. The drop in head as measured in a permeameter tube is noted for a 60-minute interval. A check run is usually made to make sure that the apparatus is working properly as leaky apparatus must be guarded against.

Table 5 shows the computed results of the load-compression and load-expansion tests. The loads and average micrometer readings are taken from table 4. The thickness of the soil cake can be determined for all loads by subtracting the average micrometer reading from the initial depth of the soil chamber, which is 0.4254 inch. If the initial micrometer reading is other than zero, it is necessary to apply a correction to each average reading before the actual thickness of the soil cake can be determined.

TABLE 5.—*Results of combined compression and permeability test on core sample no. 5, remolded at natural moisture content*

LOAD-COMPRESSION DATA

Load		Average micrometer reading	Thickness of soil cake (*d*)	Voids ratio (*e*)	Temperature (*T*)	Coefficient of permeability	
Increment	Total pressure (*p*)					For T° C. (K_T)	For 20° C. (K_{20})
	Kg per sq. cm	*Inches* $\times 10^{-4}$	*Inches* $\times 10^{-4}$		*° C.*	*Cm/sec.* $\times 10^{-6}$	*Cm/sec.* $\times 10^{-6}$
None	0	0	4,254	3.25			
First	0.048	379	3,875	2.87			
Second	.113	707	3,547	2.54	27.2	0.033	0.028
Third	.244	978	3,276	2.27			
Fourth	.634	1,347	2,907	1.90			
LOAD-EXPANSION DATA							
Third	0.244	1,299	2,955	1.95			
Second	.113	1,234	3,020	2.02			
First	.048	1,129	3,125	2.12			
None	0		[1] 3,155	2.15			

[1] Computed value

CHANGES MADE IN NOMENCLATURE

The nomenclature used in this report differs in some respects from that previously published. Changes were made for the purpose of clarity. The nomenclature is as follows:

e = voids ratio.
d = thickness of soil sample at e voids ratio.
d_0 = thickness of soil sample at zero voids ratio.
W_s = weight of dry soil.
G_s = specific gravity of soil solids.
A = cross-sectional area of compressibility chamber.
k = coefficient of permeability (general designation).
k_T = coefficient of permeability at temperature T° C.
a = cross-sectional area of permeameter tube.
$t_2 - t_1$ = elapsed time for permeability measurement.
h_1 and h_2 = the heads of water observed at times t_1 and t_2, respectively.
n_T and n_{20} = viscosities of water at $T°$ C. and 20° C., respectively.
k_{20} = coefficient of permeability corrected to 20° C.
p = pressure per unit area.
B = intercept of straight-line portion of the semilog plot of the compression curve with the 1.0 kilogram per square centimeter ordinate.
Z = slope of the compression curve when plotted on a semilog scale or change in value e for unit change of log p.
$x = 2 + \log p$.
e_1 = voids ratio under pressure p_1.
e_2 = voids ratio under pressure p_2.
d_1 = thickness of soil sample at e_1.
D_1 = thickness of field layer at e_1.
t = time, see development of formula 7, p. 261.
t_d = time required for soil sample to consolidate from e_1 to e_2.
t_D = time required for field layer to consolidate from e_1 to e_2.
IW_s = weight of immersed solid material.
V = volume of soil mass.
G_w = specific gravity of water.

The voids ratio, e, can be computed for any thickness of soil cake, d, by the formula

$$e = \frac{d}{d_0} - 1 \qquad (1)$$

The value of d_0 represents the thickness of the soil cake at zero voids ratio and is constant for any single test. It is determined from the weight of dry soil, W_s, specific gravity of soil solids, G_s, and area of soil chamber A by the formula

$$d_0 = \frac{W_s}{G_s \times A} \qquad (2)$$

Substituting the values given in table 4 for these factors for this particular test

$$d_0 = \frac{25.46}{2.60 \times 38.5} = 0.2545 \text{ centimeter or } 0.1002 \text{ inch.}$$

It is noted from table 5 that the thickness of the soil cake for the zero load of the rebound is given. Since the weight of the piston is acting on the sample as long as the micrometers are in position, this value must be computed. Usually, for stiff soils the load of the piston at the final micrometer reading is considered as zero, but in soft muck soils this assumption results in an error of measurable proportions. This thickness is computed as follows:

According to the data in table 4–A, the amount of water in the soil at the end of the test is 21.05 grams. If placed separately in the soil chamber this water will occupy a thickness of

$$\frac{21.05}{38.5\times 2.54}=0.2153 \text{ inch.}$$

Since the soil has a thickness of 0.1002 inch, the total thickness of soil cake for zero load should be 0.2153+0.1002, or 0.3155 inch. This method is sometimes used to check the results on stiff soils.

The time-compression relation is shown for the second load increment in table 4–B. The two micrometer readings were averaged and the total deformation under this load found to be 327.5×10^{-4} inches. Considering this value as 100 percent compression the corresponding percentage for all time readings are computed as shown.

The coefficient of permeability, k, is the velocity of flow in centimeters per second, feet per second, etc., at a hydraulic gradient of unity, that is, when the drop of pressure between two points in a soil column equals the horizontal distance between the points. The coefficient of permeability is dependent on temperature and, accordingly, the practice has been to correct all determined values of k to 20° C. The general formula[8] for computing the coefficient of permeability k_T is

$$k_T=\frac{2.3\ ad}{A(t_2-t_1)}\log\frac{h_1}{h_2} \qquad (3)$$

in which

k_T=coefficient of permeability at T°C.

a=cross-sectional area of the permeameter tube.

d=the thickness of the soil cake.

A=cross-sectional area of the soil cake or compressibility chamber.

t_2-t_1=time in seconds.

h_1 and h_2=heads of water acting at times t_1 and t_2, respectively.

Substitution of the values given in tables 4 and 5 gives,

$$k_T=\frac{2.3\times 0.10\times(0.3547\times 2.54)}{38.5\times 3{,}600}\log\frac{24.14}{22.94} \text{ or}$$

$$k_T=0.033\times 10^{-6} \text{ centimeters per second.}$$

The temperature of air and water during the test was 27.2° C. The correction coefficient for temperature equals $\frac{n_T}{n_{20}}$ in which n_T and n_{20} are values of the viscosity of water at T° C. and 20° C., respectively. For T=27.2° C. the correction coefficient becomes 0.844. Consequently, $k_{20}=k_T\times 0.844=0.028\times 10^{-6}$ centimeters per second.

JUDGMENT AND EXPERIENCE NEEDED IN INTERPRETING TEST DATA

With proper equipment no difficulty should be encountered in performing the compression test or in expressing the results. In contrast, however, interpretation of the test data is a matter of judgment and experience that does not lend itself so readily to standardization. The basis of the engineer's judgment is his opinion of the extent to which the conditions of test represent those produced by the environment of the particular soil stratum in place.

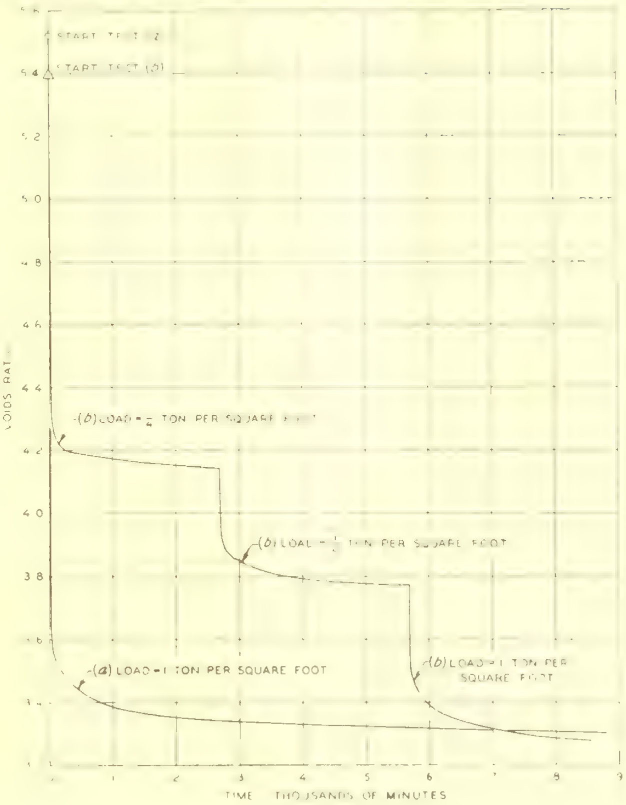

FIGURE 9.—EFFECT OF NUMBER OF LOAD INCREMENTS ON VOIDS RATIO OF MUCK SOIL.

The methods used in computing the moisture contents and the settlements are described in detail because they call attention to some of the considerations that influence the interpretation of the test data.

The following method of applying the test data has been used. Other methods might have been used, but the method described was chosen as suitable in this case, since the relative effect of the compression and sliding that occurred in the undersoil during placement of the fill could not be determined. Also, it was not known whether the core samples represented the muck as it existed before the construction of the fill, or in some condition of partial disturbance caused by the fill construction. In this analysis assumptions were made as follows:

1. The compression is direct, with no lateral flow involved after completion of the fill.
2. The muck bed had reached a state of ultimate consolidation caused by its own weight before placement of the fill and was in natural undisturbed state.
3. The weight of muck in the original layer is equivalent to that of a material having a specific gravity of 2.6 and a voids ratio as indicated by the load-compression curve.
4. Hydrostatic uplift exists below mean water level or zero elevation.
5. The effective weight of the gravel fill is 110 pounds per cubic foot above zero elevation and 68.5 pounds per cubic foot below zero elevation. The effective weight

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[8] For derivation of this formula see Soil Mechanics Research, by Dr. Glennon Gilboy, Proceedings American Society of Civil Engineers, vol. 57, no. 8, October 1931.

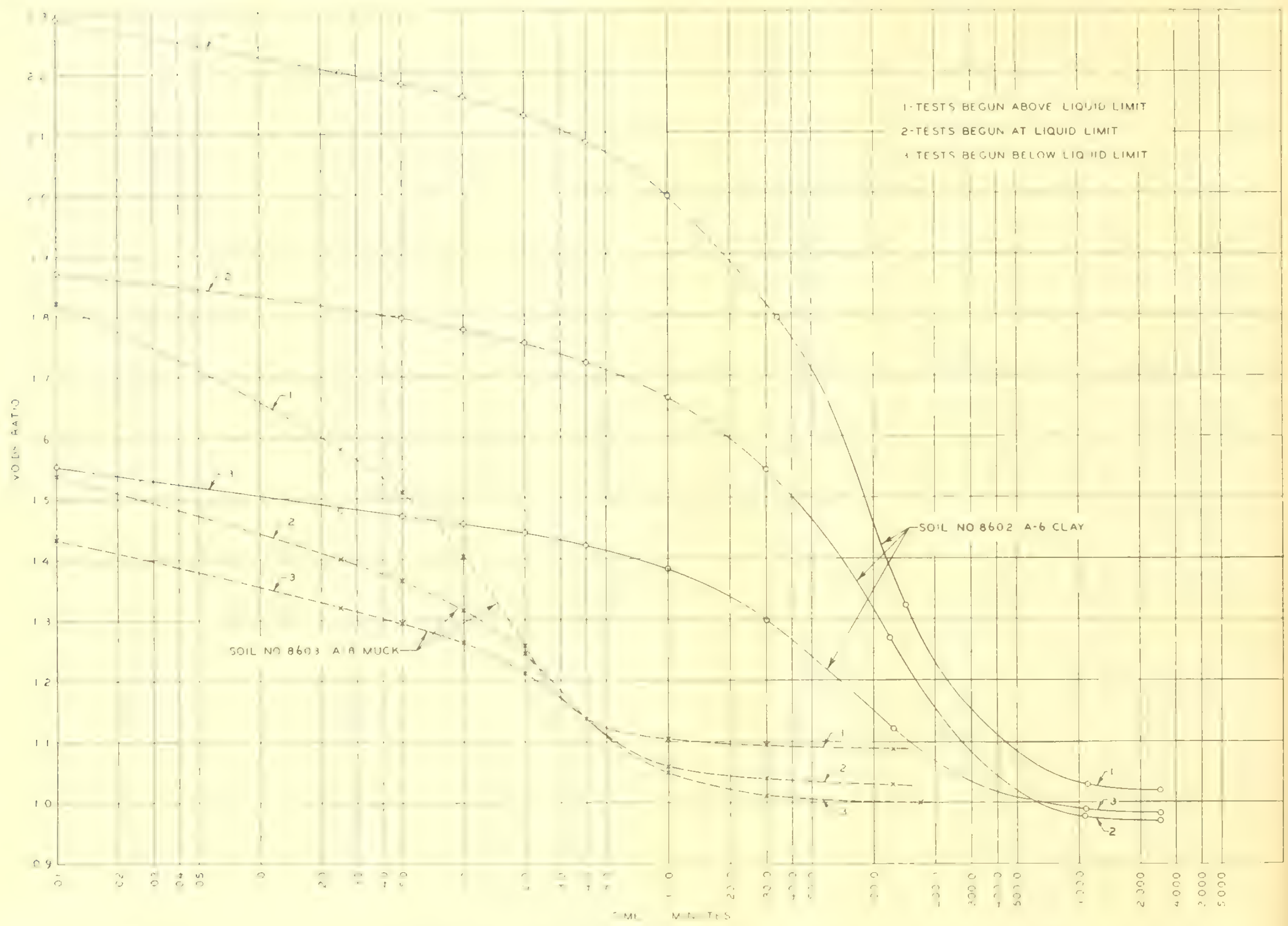

FIGURE 10.—EFFECT OF INITIAL MOISTURE CONTENT ON RESULTING VOIDS RATIO UNDER A PRESSURE OF 2 TONS PER SQUARE FOOT.

of displaced muck is 54 pounds per cubic foot above zero elevation and 33 pounds per cubic foot below zero elevation.

6. In computing the moisture contents, the loads were assumed to equal the weight of the materials above the sample location as disclosed by the test borings, and the period during which these loads were acting was assumed to be 6 months.

7. The average of the voids ratios, taken at 1-foot intervals from top to bottom of the muck layer, was used in computing the fill settlement. The actual voids ratios at the location of the particular sample, in contrast, were used in computing the moisture contents.

8. The load-compression curve discloses the relation between load and voids ratio within the load range shown, regardless of (*a*) the number of increments in which the load is applied, and (*b*) the moisture content of the muck at the start of the test, provided the pores are entirely filled with moisture. This assumption is warranted by the results of studies made in the Bureau's soils laboratory.

The results of two compression tests on a muck soil are shown in figure 9, in which voids ratios are plotted against time. In test "a", starting at a voids ratio of about 5.52, the sample was compressed under a load of 1 ton per square foot for about 6 days. The final voids ratio was about 3.30. In test "b", starting at a voids ratio of about 5.39, the sample was compressed under the same load applied in 3 increments as shown, each increment acting for about 2 days. The final voids ratio was about 3.27, varying less than 1 percent from that of test "a."

INITIAL MOISTURE CONTENT FOUND TO AFFECT ULTIMATE COMPACTION BUT SLIGHTLY

The results of two sets of compression tests started at different moisture contents are shown in figure 10. To facilitate the comparison, time is plotted on a logarithmic scale. The three initial moisture contents for each set are designated "above the liquid limit", "at the liquid limit", and "below the liquid limit." A load of 2 tons per square foot was used in each test. The two soils, an A–6 clay and A–8 muck, represent two types of material commonly encountered in settlement problems.

The variation in the resulting voids ratios of the three tests on the clay soil is the difference between 1.02 and 0.97 or 0.05, a variation of about 5 percent. Those of the muck show a variation in voids ratios of 0.09, or about 9 percent. It should be noted that the curves for the muck come together at about 4 minutes, and the curve for test 1 is practically horizontal from that point on, indicating the probability of some sticking in the machine. Also, although the muck tests were continued for as long a time as the clay tests, they were plotted only to about 150 minutes because they are practically horizontal beyond that point. It is apparent from these tests that the final voids ratio is not appreciably dependent on the initial moisture content.

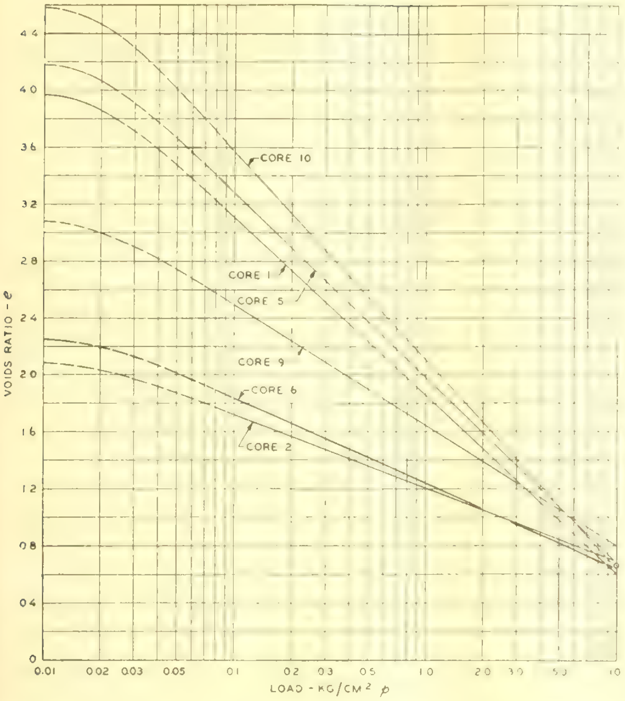

Figure 11.—Load-Compression Curves of Undisturbed Core Samples.

9. At any stage of loading, equilibrium between load and pores, as disclosed by the load-compression curve, exists throughout the depth of any muck layer.

10. The average time-compression curve that is used discloses the relation between duration of load increment and percentage of compression caused by any load increment within the load range of 0.01 ton per square foot and that required to compress the soil to its plastic limit.

A study of the time-compression data for different load increments discloses that no two of the several curves determined for each test are identical. However, variations between the curves are independent of load increment and no apparent relation exists. Generally the average of the several sets of data furnishes a curve within 10 percent of any individual curve at all time ordinates. Consequently, it seems practical to make use of this average curve.

FORM OF TYPICAL LOAD-COMPRESSION CURVES DETERMINED

Comprehensive study of all the compression test data furnished by the Bureau's investigations discloses that, when plotted to a semilogarithmic scale, the load-compression relation generally results in a curve that becomes a straight line for loads greater than 0.1 kilogram per square centimeter. Figure 11 shows the compression test data for the soils used in this analysis.

For values of p greater than 0.1 kilogram per square centimeter the data results in straight lines of the form

$$e=B-Z \log p \quad \text{-----} \quad \text{-----} (4)$$

in which B is the intercept of the straight-line portion of the curve at the 1.0 kilogram per square centimeter ordinate, and $-Z$ is the slope of the semilog plot of the curve, or range in value e for unit change of $\log p$. Z may be termed the "compression index" of the soil.

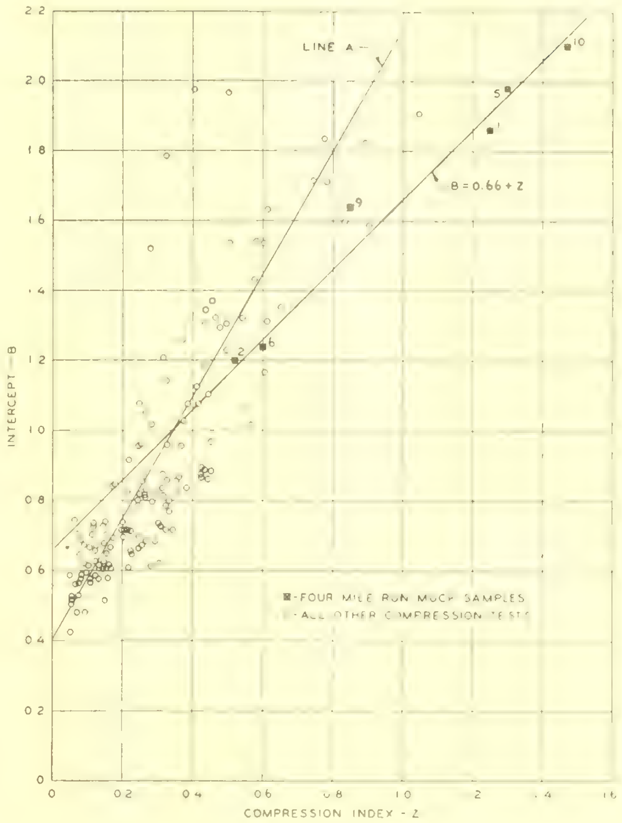

Figure 12.—Relation Between Compression Index and Intercept.

The relation between the slopes and intercepts for the mucks used in this analysis are plotted in figure 12, and are found to conform closely to the formula

$$B=0.66+Z \quad \text{------} \quad \text{--------} (5)$$

The relations between the slopes and intercepts of a great number of load-compression curves are also plotted in figure 12, and are very roughly represented by line A.

Figure 13 shows a very general relation between the compression index Z and the liquid limit of the mucks used in this analysis. This fact makes possible a short and approximate method of estimating settlements which will be discussed later.

For pressures less than about 0.1 kilogram per square centimeter the load-compression relation may vary from a horizontal line to a curve of form depending upon such factors as:

1. The degree of consolidation of the sample at the beginning of the test.
2. The degree to which the surfaces of the sample were disturbed during its transfer from the core container to the testing apparatus.
3. Experimental errors caused by friction or by characteristics of the testing apparatus.

Were the effect of these and possibly other influences removed, the straight-line portion of the semilog plot of the curve for loads greater than 0.1 kilogram per square centimeter could be extended for loads less than 0.1 kilogram per square centimeter until a maximum voids ratio equal to that of the soil immediately after

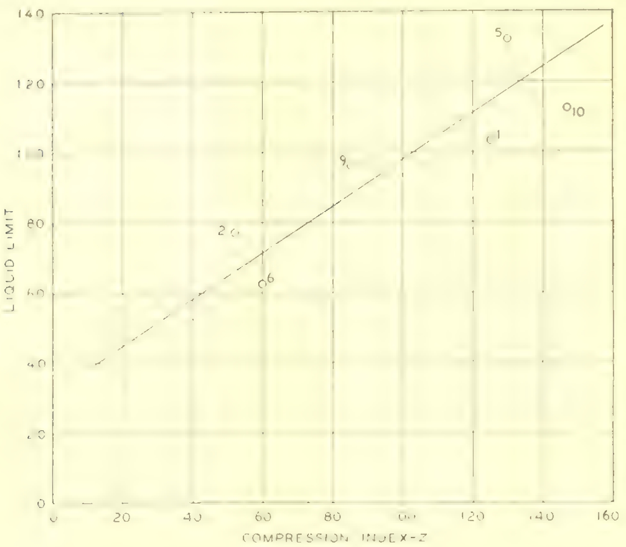

Figure 13.—Relation Between Liquid Limit and Compression Index.

settling out of suspension is reached. Flocculation tests[9] performed on similar materials indicate that for a soil similar to that of core 5, the maximum voids ratio would be about 7.0.

This high voids ratio, however, exists but temporarily. A better starting point is the voids ratio that the top of a sediment will ultimately attain due entirely to the weight of the soil particles in a layer of single-particle thickness and not influenced by the load resulting from an accumulation of particles above this increment.

The exact value of this voids ratio would be difficult to determine in all instances. Therefore the compression curves plotted for all the tests performed in the Bureau's subgrade investigations were studied to determine some general form of curve that could be used for practical purposes to express, approximately, the relation of voids ratio to load for loads of less than 0.1 ton per square foot.

It was found that such a curve, extending to a voids ratio high enough to satisfy the requirements of practical application, has the form of the broken lines in figure 11. This curve is expressed by the following empirical formula, the numerical constants of which were evaluated by the method of least squares.

$$e=B+Z(1.69-1.07x^2+0.38x^3) \qquad (6)$$

in which

e = voids ratio for loads between 0.01 and 0.10 kilogram per square centimeter.

B = intercept of the straight-line portion of the semilog plot of the curve at the 1.0 kilogram per square centimeter load ordinate.

$-Z$ = slope of the semilog plot of the straight-line portion of the curve, or range in value e for unit change in log p.

$x=2+\log p$.

Using this formula the voids ratios corresponding to various loads between 0.01 kilogram per square centimeter and 0.10 kilogram per square centimeter for the mucks in this analysis are as shown in table 6.

The broken-line curves in figure 11, for loads smaller than 0.1 kilogram per square centimeter, and the solid-line curves for loads greater than 0.1 kilogram per square centimeter, are assumed, therefore, to express the relation of voids ratio to load between small or zero loads and loads at the plastic limits. There is a general tendency for all of the curves to intersect in a common point corresponding to a voids ratio of about 0.66 on the ordinate for 10 kilograms per square centimeter.

RELATIVE RATES OF CONSOLIDATION OF SOIL STRATUM AND SOIL SAMPLE COMPARED

The time-compression curves used in this analysis are shown as semilogarithmic graphs in figure 14. These curves are the averages of the individual time-compression curves for different load increments after certain ones had been eliminated because of obvious error.

Before using the curves in figure 14, in estimating the speed of consolidation of soil strata in place there must be determined the relative periods of load application at which equal percentages of compression occur in the soil strata and in their representative laboratory samples.

Table 6.—*Characteristics of compression curves for undisturbed muck samples*

Material from core no.	B	Z	Voids ratio, e, for the following loads					
			0.010 Kg per sq. cm	0.015 Kg per sq. cm	0.02 Kg per sq. cm	0.04 Kg per sq. cm	0.07 Kg per sq. cm	0.10 Kg per sq. cm
1	1.86	1.25	3.97	3.93	3.86	3.59	3.30	3.11
2	1.20	.52	2.08	2.06	2.03	1.92	1.80	1.72
5	1.98	1.30	4.18	4.14	4.06	3.78	3.48	3.28
6	1.24	.60	2.25	2.23	2.20	2.07	1.93	1.84
9	1.64	.85	3.08	3.05	3.00	2.82	2.62	2.49
10	2.10	1.47	4.58	4.54	4.46	4.14	3.80	3.57
Values of $(1.69-1.07x^2+0.38x^3)$ for these loads			1.69	1.66	1.60	1.38	1.15	1.00

The determination is made on the basis of the time required for a unit volume of water to travel a unit distance through the soil pores and for the conditions (see fig. 15) met in this report. The method is as follows:

Case 1.—Water free to flow from both top and bottom of the soil stratum.

Let e_1 = voids ratio of both soil sample and soil stratum before compression, under pressure of p_1.

e_2 = voids ratio of soil sample and soil stratum after compression by pressure p_2.

d_1 = thickness of the soil sample at e_1. (See formula (1).)

D_1 = thickness of the soil layer at e_1.

t = average time required for a unit volume of water to travel a unit distance through the soil during the change from e_1 to e_2.

t_d = time required for the soil sample to consolidate from e_1 to e_2.

t_D = time required for the soil layer to consolidate from e_1 to e_2.

The total units of water volume to be squeezed out of the laboratory sample per unit of cross-sectional area equals $\frac{e_1-e_2}{1+e_1}d_1$, one half of which flows out of each face. The average distance traveled by each unit of water equals $\frac{d_1}{4}$.

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[9] For procedure see Subgrade Soil Testing Methods, by C. A. Hogentogler and E. A. Willis, proceedings of the A. S. T. M., 1934.

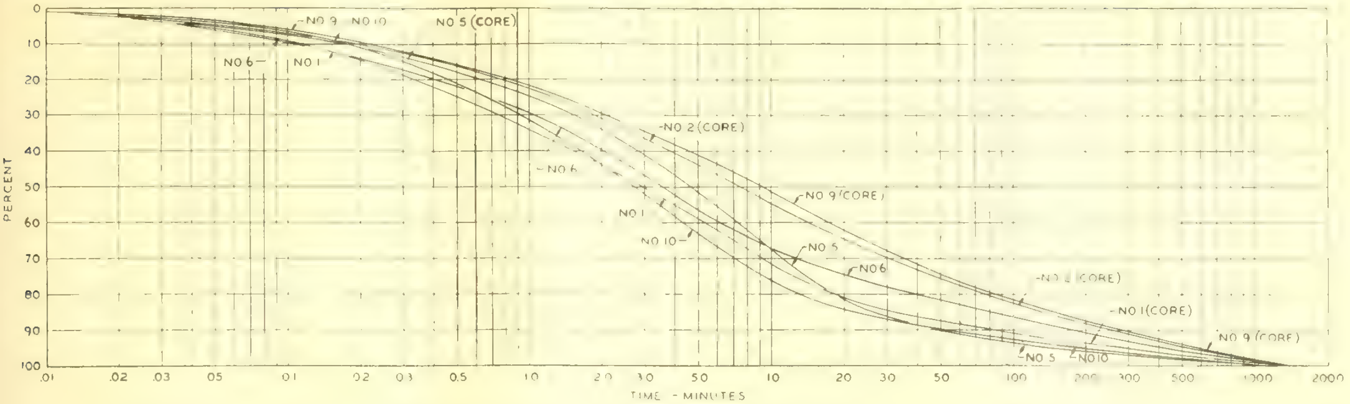


Figure 14.—Average Time-Compression Curves of Undisturbed Cores from Hydraulic Fill.

Therefore the time required for the laboratory sample to consolidate from a voids ratio of e_1 to e_2 is

$$t_d=\frac{e_1-e_2}{1+e_1}\times\frac{d_1}{2}\times\frac{d_1}{4}t$$

In the same manner the time required for the soil stratum of thickness D_1 to consolidate an equal amount is

$$t_D=\frac{e_1-e_2}{1+e_1}\times\frac{D_1}{2}\times\frac{D_1}{4}\times t$$

Then

$$\frac{t_d}{t_D}=\frac{d_1^2}{D_1^2} \qquad (7)$$

Case 2.—Water free to flow out of but one face, either top or bottom of the soil stratum.

In this case all of the water or $\frac{e_1-e_2}{1+e_1}\times D_1$ units per unit area of soil face must escape in one direction and the average distance it travels is $\frac{D_1}{2}$. Then the time of consolidation of the soil stratum becomes

$$t_D=\frac{e_1-e_2}{1+e_1}\times D_1\times\frac{D_1}{2}\times t$$

and

$$\frac{t_d}{t_D}=\frac{d_1^2}{4D_1^2} \qquad (8)$$

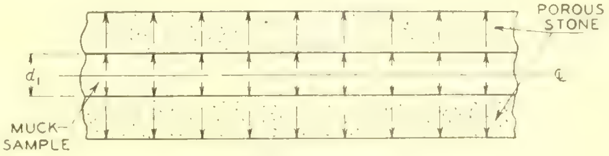
STATE OF CONSOLIDATION OF MUCK SAMPLES PRIOR TO FILL CONSTRUCTION IMPORTANT

This analysis involves four distinct computations, which are: (*a*) State of consolidation of the muck deposit prior to the fill construction; (*b*) elevation of the top of the muck layer immediately after completion of the fill; (*c*) amount and rate of subsequent consolidation produced by the fill material; and (*d*) the moisture content of the muck at the locations from which cores were obtained.

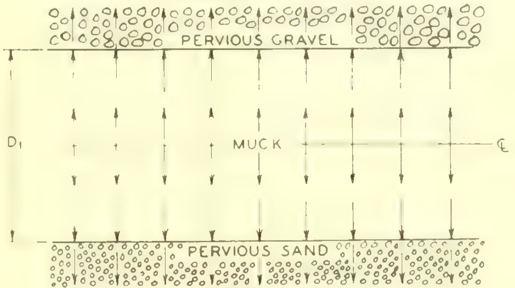
The layer of muck at the location of boring S–6 from which core 5 was taken, had a bottom elevation of −15.9 feet when the borings were made and a top elevation of −3.0 before construction. Since it is not likely that the elevation of the firm sand under the muck changed appreciably during the construction of the fill it seems reasonable to assume that the thickness of the muck layer was 12.9 feet prior to construction.

The consolidation of the muck layer caused by the weight of the soil solids alone is estimated as follows:

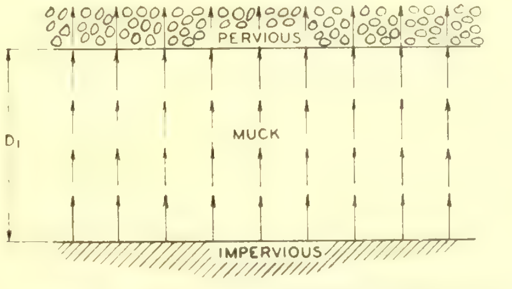
At any voids ratio the weight of the solid material in a volume of the muck below water level is given by the formula



LABORATORY SAMPLE



CASE 1 - MUCK LAYERS WITH PERVIOUS LAYERS ON TOP AND BOTTOM



CASE 2 - MUCK LAYER WITH PERVIOUS LAYER ON TOP AND IMPERVIOUS LAYER ON BOTTOM

Figure 15.—Means by Which Water Escapes from Muck in Laboratory Sample and in Fill.

$$IW_s=V\frac{1}{1+e}(G_s-G_w) \qquad (9)$$

in which

IW_s = the weight of the immersed solid material.
V = the volume.
e = the voids ratio.
G_s = the specific gravity of the soil, in this case 2.6.
G_w = the specific gravity of water, in this case 1.

At elevation −3.0 under zero load the voids ratio for core 5, from the load-compression relation, table 6, is 4.18 and at a depth of 1 foot (30.48 centimeters) the pressure would be

$$30.48\times\frac{1}{1+4.18}\times(2.6-1)\times\frac{1}{1{,}000}=0.0094$$ kilograms per square centimeter.

This pressure, according to assumptions used in developing a standard form for the load-compression curve (see complete work sheet, fig. 16) cannot further consolidate the layer and consequently the voids ratio at elevation −4.0 is 4.18, the same as at elevation −3.0.

The combined weight of the first 2 feet of muck is 0.0094+0.0094 or 0.0188 kilograms per square centimeter, which is the pressure acting at elevation −5.0. Proper substitution in formula (6), or reading directly on the corresponding curve, figure 16, shows that this load can consolidate the sample to a voids ratio of 4.08.

Continuation of this process provided the data of table 7 and figure 16D, which shows the pressures acting at all locations throughout the thickness of the muck deposit before the fill construction.

LENGTH OF TIME REQUIRED FOR COMPLETE FILL SETTLEMENT DETERMINED

The computations were based on the assumption that the muck bed was completely consolidated by its own weight. According to formula (7) the greater the thickness of the layer the longer will be the time required for complete consolidation. To test the validity of this assumption, the greatest possible length of time required for complete settlement must be known. For computing this, the maximum possible thickness that the soil deposit could ever have had must be used. This is derived as follows:

The average voids ratio of the deposit as determined by averaging the voids ratios shown in table 7 is 3.60. It may then be assumed that the voids ratio of the muck layer during the course of natural consolidation under its own weight changed from 4.18 to an average of 3.60. This means that every increment of thickness in the layer would have retained a voids ratio of 4.18 had it not been required to carry the load imposed by additional deposits. It may be assumed that the maximum thickness of the deposit never exceeded that represented by a voids ratio of 4.18.

TABLE 7.—*Degree of consolidation of material prior to construction at point where core 5 was taken*

Elevation (feet)	Thickness	Total muck load (p)	Voids ratio	Load increment per foot depth
	Feet	*Kg per sq. cm*		*Kg per sq. cm*
−3	0	0	4.18	0.0094
−4	1	0.0094	4.18	.0094
−5	2	.0188	4.08	.0096
−6	3	.0284	3.94	.0099
−7	4	.0383	3.80	.0102
−8	5	.0485	3.68	.0104
−9	6	.0589	3.58	.0106
−10	7	.0695	3.49	.0109
−11	8	.0804	3.40	.0111
−12	9	.0915	3.33	.0113
−13	10	.1028	3.27	.0114
−14	11	.1142	3.21	.0116
−15	12	.1258	3.15	.0117
−15.9	12.9	.1363	3.11	(1)
Average			3.60	

[1] (0.9×0.0117=0.0105.)

If the muck layer, with an original voids ratio of 4.18, were compressed to a voids ratio of 3.60 and a thickness of 12.9 feet, then its original thickness may be computed from the formula

$$\frac{1+e_1}{1+e_2}\times D_2=D_1\text{ - - - - - - - - - - - - - -(10)}$$

in which e_1 is the original voids ratio, in this case 4.18, corresponding to a thickness of D_1, and e_2 is the voids ratio of the compressed material, in this case 3.60, corresponding to a thickness, D_2, of 12.9 feet.

Then

$$D_1=\frac{1+4.18}{1+3.60}\times 12.9=14.5\text{ feet.}$$

The manner in which the formation of the muck deposit took place is a matter of conjecture. To estimate the time of ultimate settlement of the muck deposit, it may be assumed that the layer was originally 14.5 feet thick with a uniform voids ratio of 4.18. According to the test data the thickness of the laboratory sample at this voids ratio would have been 0.51 inch and equilibrium under its own weight was reached in 1,200 minutes. The time required for the consolidation of the muck deposit is computed from formula (7) as follows:

$$t_D=\frac{t_d\times D_1^2}{d_1^2}=\frac{1{,}200\times(12\times 14.5)^2}{0.51^2}=140{,}000{,}000\text{ minutes}$$

or about 270 years.

Geologists have estimated the age of the muck layer at Four Mile Run as several thousand years. According to what precedes, it would take about 270 years for the completion of consolidation caused by its own weight.[10] Consequently, the assumption that 100 percent consolidation has occurred within the muck layer at the location of core 5, prior to fill construction, is well founded.

Similar computations were made for boring S–9, located 264 feet to the left of the centerline, station 183+00, where core 6 was obtained. The computed time of complete settlement at this location was 2,230 years, the greatest for any location at which borings were made. This is considered as within the estimated age of the muck. Therefore, the assumption that complete consolidation caused by its own weight had occurred throughout the muck layer prior to fill construction is consistent.

TYPICAL METHOD OF ANALYSIS FOR SECTION UNDER FILL LOAD

According to table 7 the average voids ratio of the muck layer at boring S–6 is 3.60, which corresponds to a load of 0.057 kilogram per square centimeter acting until consolidation under this pressure is complete.

The results of borings made 6 months after fill construction are shown in figure 16C. According to this figure the muck at this time supported a gravel layer 9.0 feet thick and had a top elevation of −4.9 feet as compared with −3.0 feet before the improvement was begun.

Assuming that the gravel layer does not consolidate, it will have a constant thickness of 9 feet acting continuously after fill construction. Consequently, the difference between −4.9 and −3.0 must be accounted for by a change in thickness of the muck layer.

The muck will, of course, consolidate under load.

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[10] This value is not to be confused with the time of ultimate consolidation under the fill of 243 years subsequently determined. The value of 270 years represents the computed time for complete consolidation of the muck caused by its own weight acting within the layer itself. It is based on a layer 14.5 feet thick. The value of 243 years represents the time required for the muck layer to reach complete consolidation due to the superimposed gravel fill, and is based on a layer only 12.2 feet thick.

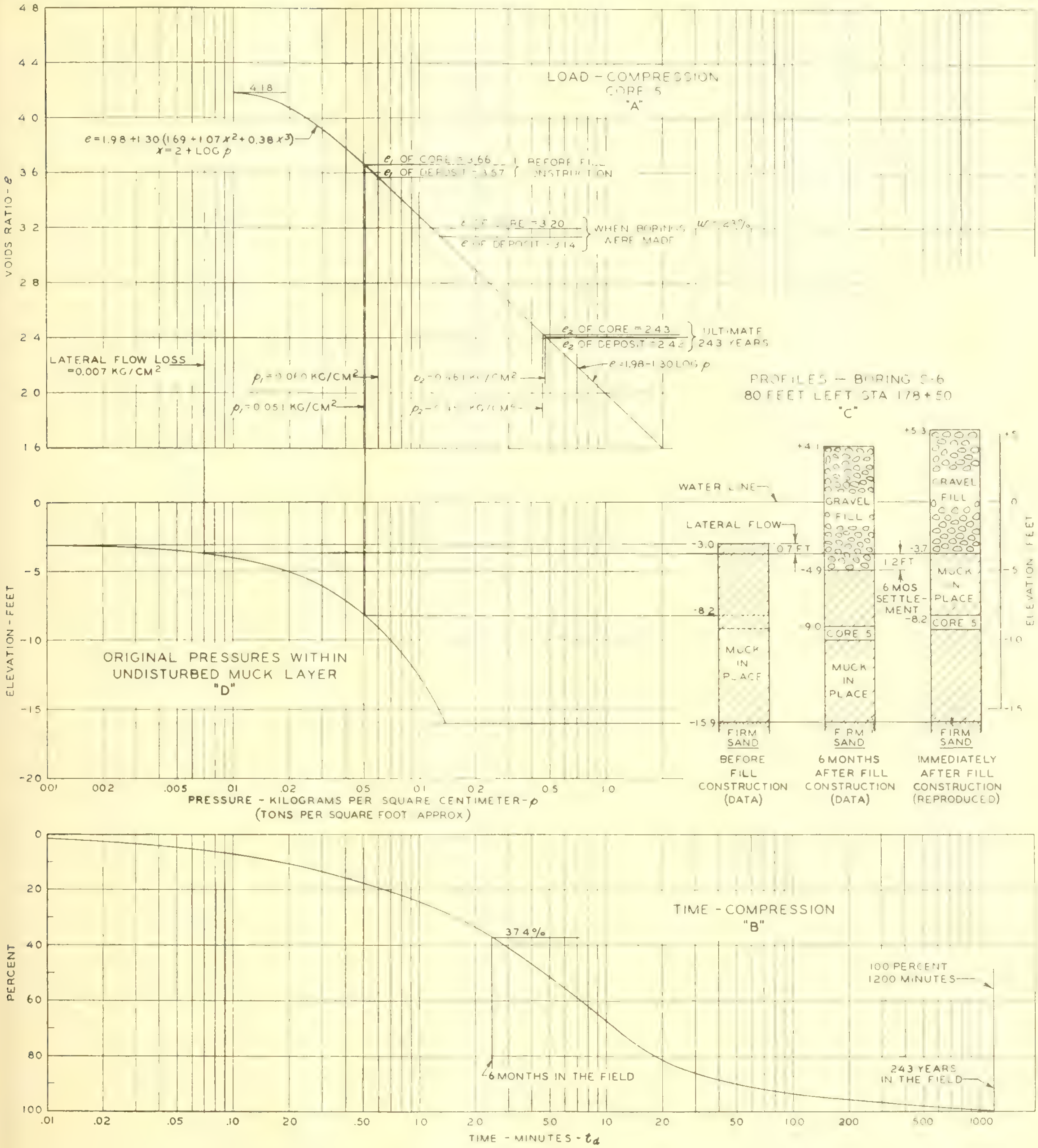

Figure 16.—Graphical Analysis of the Compression Test Data of Undisturbed Material from Core No. 5.

Furthermore, there is a possibility that during the pumping operations a portion of the muck layer was displaced laterally. No measurements were made to determine the extent of lateral flow during construction. The thickness of the muck layer displaced in this manner, therefore, must be determined by a series of approximations before the analysis of settlement can be completed.

Had no lateral flow occurred, the gravel fill when first constructed would have rested on top of the muck layer shown in figure 16C, left. The effect of the fill acting for 6 months would be to reduce the thickness of the muck layer by an amount indicated by the load-compression and time-compression curves.

The thickness of the muck layer disclosed by the boring subtracted from the computed reduced thickness gives an estimate of the thickness of the material displaced by lateral flow.

Because of this loss of material both the thickness of the muck layer and the load acting on it immediately after construction are less than those used in the first computation. Consequently, a second approximation is made using a revised thickness and load. This process is repeated until the computed thickness practically equals that determined by the borings.

The results of such computations, shown in figure 16, were obtained in the following manner. The load imposed by the gravel fill, 6 feet above water at 110 pounds per cubic foot and 3 feet below water at 68.5 pounds per cubic foot was computed to be 0.422 kilogram per square centimeter. The average voids ratio of 3.60 referred to above equals that produced by a load of 0.057 kilogram per square centimeter compressing the sample for a long time.

This load of 0.057 kilogram per square centimeter is not the average load acting throughout the depth of the deposit. It is the load acting on top of a layer of zero weight that will produce a voids ratio equal to the average voids ratio produced by the variable load distributed through the deposit.

The total effective load acting on top of the layer is $0.057+0.422=0.479$ kilogram per square centimeter. This will ultimately consolidate the sample to an average e_2 of 2.40 (equation (4) or fig. 16). The difference in voids ratio produced by the additional load equals $3.60-2.40$ or 1.20.

The percentage of consolidation which will occur in 6 months may be obtained from formula (7) and the time-compression curve. The thickness, D_1, of the muck layer was 12.9 feet. The thickness of the laboratory sample, d_1, corresponding to the average voids ratio of 3.60 is 0.452 inch. The time of settlement of the muck layer in place, t_D, is 6 months. Substitution of these values in formula (7) indicates that the time in the laboratory, t_d, in which the same percentage of compression will be accomplished, is 2.24 minutes. This according to the time-compression curve, figure 16B, corresponds to 35.7 percent. Consequently, the amount of additional compression accomplished in 6 months is represented by a change in voids ratio of 35.7 percent of 1.20 or 0.43. The reduced voids ratio of the muck layer is therefore the initial voids ratio 3.60 minus the reduction 0.43, or 3.17.

This is indicative of a thickness of muck layer 6 months after fill construction of

$$12.9\times\frac{1+3.17}{1+3.60}=11.7 \text{ feet}$$

The boring (fig. 16C, middle) shows that the muck layer was actually 11.0 feet thick at this time. It is apparent, therefore, that approximately 0.7 foot of muck had been laterally displaced. At what point or points within the muck layer this amount was lost is not known. However, it is obvious that the least stable portion of the muck would be displaced. The top of the layer has the highest voids ratio, according to table 7, and therefore the least density and least resistance to lateral flow. In subsequent computations, it is assumed that 0.7 foot of muck was removed from the top of the layer.

The second approximation is therefore made on the assumption that the muck layer is only 12.2 feet thick instead of 12.9 feet thick. This has the effect of increasing the amount of gravel under water to 3.7 feet and decreasing the amount of gravel above water to 5.3 feet. The load produced by the gravel in this position is 0.408 kilogram per square centimeter.

A further effect of the removal of 0.7 foot of muck is a change in the average voids ratio of the muck layer, as the material removed according to preceding assumptions had a voids ratio of 4.18 against the average of 3.60. This results in a lower average voids ratio, equaling 3.57 in this case, corresponding to a compression load of 0.060 kilogram per square centimeter. The weight of the displaced muck equals 0.7×0.0094 or 0.007 kilogram per square centimeter. The total load is thus $0.408 + 0.060 - 0.007$ or 0.461 kilogram per square centimeter. According to the load-compression curve, figure 16A, this load will ultimately produce a voids ratio of 2.42.

Continuing the computations as in the first approximation, it is found that the reduced thickness of muck layer, 6 months after fill construction, becomes 11.0 feet, which is the thickness as determined from the borings.

Consequently, the revised profile showing conditions immediately after fill construction (fig. 16C, right) is constructed on the basis of a muck layer 12.2 feet thick.

SETTLEMENT ANALYSIS COMPLETED AND MOISTURE CONTENT OF SAMPLE ESTIMATED

In the same manner that the thickness of 11.0 feet was computed for a period of settlement of 6 months under a load of 0.461 kilogram per square centimeter, thicknesses may be computed for any desired period up to the time of ultimate settlement. By proper substitutions in formula (7) the period of time required for ultimate settlement, $e_2=2.42$, may also be determined. Results of such computations are shown in table 8.

The moisture content of core 5 was determined from a sample taken from the top of the core shown in figure 16C, middle, at an elevation of −9.0, or 6.9 feet above the sand layer. The core was taken 6 months after fill construction. The muck layer, 12.2 feet thick immediately after fill construction, had consolidated to a thickness of 11.0 feet. Consequently, the position of the top of sample 5 immediately after fill construction was approximately $\frac{6.9\times12.2}{11.0}$ or 7.7 feet above the sand layer, which corresponds to an elevation −8.2 as shown in figure 16C, right.

TABLE 8.—*Computed settlement for different periods of time*

Period of settlement (months)	Average voids ratio	Consolidation	Computed thickness	Computed settlement
		Percent	*Feet*	*Feet*
0	3.57	0	12.2	0
1	3.38	16.1	11.7	0.5
6	3.14	37.4	11.0	1.2
12	2.98	51.2	10.6	1.6
20	2.84	62.8	10.3	1.9
36	2.69	76.1	9.9	2.3
Maximum [1]	2.42	100.0	9.1	3.1

[1] Occurs in 243 years' time.

From table 7, the voids ratio at elevation −8.2 is found by interpolation to be 3.66, which corresponds to a load of 0.051 kilogram per square centimeter on the load-compression curve, figure 16A. This, minus the load of 0.007 kilogram per square centimeter lost by lateral flow and added to the fill load of 0.408 kilogram per square centimeter, makes a total load of 0.452 kilogram per square centimeter acting on the sample. Ultimately this will consolidate the sample to a voids ratio of 2.43, causing a decrease in voids ratio equal to 3.66−2.43, or 1.23.

The percentage of consolidation that occurs in 6 months in this sample is 37.4 percent or the same as that occurring in the entire layer as shown in table 8. Therefore, the voids ratio of the sample after 6 months equals 3.66−(1.23×0.374)=3.20. This corresponds to a moisture content of $\frac{3.20}{2.6}\times 100$, or 123 percent, as compared with the moisture content of 125 percent as actually determined in the sample.

The computed moisture contents shown in table 2 and the computed settlement shown in table 3 and figure 7 were determined in the manner described above.

METHODS OF COMPUTING FILL SETTLEMENT DISCUSSED

The method of computing the settlements in this report was adopted after much preliminary work in which other somewhat similar methods were tried and rejected after analyzing their suitability and reliability.

Most of the work of estimating probable settlement of loaded soil layers rightfully belongs in the field of foundation engineering. Problems in this field generally differ from that studied at Four Mile Run, since the loads are transmitted from building to soil by footings, rafts, piling, etc. There is no uniform loading, such as is produced by a fill, and the compressible layers are usually under appreciable topsoil overburden. This makes the determination of the pressures quite a difficult problem and lessens the importance of variations in voids ratios in the layer. The voids ratio of a core taken within the layer is generally assumed as the voids ratio of the layer. Additional data on foundation settlement estimation from compression tests have been published.[11]

A simpler method of computing settlements is to use the natural moisture content and corresponding voids ratio of the undisturbed sample as the initial voids ratio, e_1, and determine the ultimate voids ratio, e_2, to which the layer would compress under load, directly from the load-compression curve. Having the total settlement, one can determine the settlement occurring after any given time interval.

This method gives fairly accurate results for most of the locations discussed in this report. However, research along more accurate lines had to be performed to determine the validity of various methods. For study of conditions at Four Mile Run the more accurate method seemed desirable. The muck bed at that location was sampled after it had undergone some 6 months of compression under the fill load instead of prior to construction, as would be the case in a general investigation of settlement. This alone indicated a need for a special method of computation.

The wide range of voids ratios existing in the layer from top to bottom was a further indication of the need for the more accurate procedure. According to table 7 the theoretical voids ratio of a sample from elevation −5.0 would have been about 4.08 prior to fill construction. A sample from elevation −15.0 would be expected to have a voids ratio of 3.15. In the case of a deeper layer the voids ratio of the muck at elevation −40.0 would be about 2.40. The actual core sample in this case was taken from the muck at elevation −9.0 after 6 months compression under load. Calculations based on the moisture-content determination indicate that this material was at elevation −8.2 prior to fill construction. Table 7 shows that sample 5 would have had a voids ratio of about 3.66 at that time, corresponding to a natural moisture content of 141 percent.

This value happens to be quite close to the average voids ratio of 3.60 determined for the layer. Therefore, in this particular case there is little difference in the settlement determined by either method. However, the use of test results from core 5 material in the computations for all points used where settlement comparisons were made would have necessarily yielded much more inaccurate results for the thicker portions of the muck bed, since the average initial voids ratios decrease with an increase in thickness. The settlement estimated by this simple method decreases as the voids ratio of the sample decreases. The degree of error introduced by the method depends on the difference between the voids ratio of the sample and the average voids ratio of the deposit.

For example, the total settlement at the location of core 5 based on a sample taken at elevation −5.0 equals about 32 percent of the thickness; that based on a sample taken at elevation −15.0 is only 21 percent of the layer thickness. In this instance the settlement estimated by the simpler method (sample taken at elevation −8.2) becomes 27 percent as compared to the value determined by the adopted method, of about 25 percent. It is interesting to note that the computed settlement based directly on core 5 test data without a 6-months correction is 21 percent of the layer thickness, or that indicated by the material sampled at −15.0.

TABLE 9.—*Settlement computations by 1-foot increments for boring S–6 based on core no. 5*

Elevation (feet)	Thickness	Total muck load	Voids ratio	Average voids ratio for each foot	Total muck load (averaged)	Total load gravel and muck load	Resulting voids ratio	Resulting thickness of 1-foot layer
	Feet	*Kg per sq. cm*			*Kg per sq. cm*	*Kg per sq. cm*		*Feet*
−3	0	0	4.18	...	....	0.4225	.	.
−4	1	0.0094	4.18	4.18	0.0047	.4272	2.47	0.67
−5	2	.0188	4.08	4.13	.0141	.4366	2.46	.67
−6	3	.0284	3.94	4.01	.0236	.4461	2.44	.69
−7	4	.0383	3.80	3.87	.03335	.45585	2.43	.70
−8	5	.0485	3.68	3.76	.0434	.4659	2.41	.72
−9	6	.0589	3.58	3.63	.0537	.4762	2.40	.73
−10	7	.0695	3.49	3.535	.0642	.4867	2.39	.75
−11	8	.0804	3.40	3.445	.07495	.49745	2.37	.76
−12	9	.0915	3.33	3.365	.08595	.50845	2.36	.77
−13	10	.1028	3.27	3.30	.09715	.51965	2.35	.78
−14	11	.1142	3.21	3.24	.1085	.5310	2.33	.79
−15	12	.1258	3.15	3.18	.1200	.5425	2.32	.79
−15.9	12.9	.1363	3.11	3.13	.13105	.55355	2.31	.72
Average or total	......	...	3.60				2.39	9.54

Table 9 presents evidence that the use of the average voids ratio, as determined in table 7, in computing settlements gives the same result as a summation of the compression of each 1-foot increment determined separately. In table 9 the average voids ratios for each 1-foot layer are given with the corresponding load increments and total loads. The resulting ultimate voids ratios are determined from the load-compression relation and the compressed thickness of each increment is obtained in the same manner as before. A value of total ultimate thickness of 9.54 feet is obtained as compared with the value of 9.53 feet obtained by the use of the average voids ratio of the entire layer. The average of the final voids ratios derived by this foot-by-foot determination is 2.39, while that determined from the average voids ratio of the entire layer is 2.40.

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[11] Progress Report of Special Committee on Earth and Foundations, Proceedings American Society of Civil Engineers, May 1933.

SETTLEMENTS MAY BE ESTIMATED BY AN APPROXIMATE METHOD

The relations established in the foregoing analysis suggest an approximate method for rapidly estimating settlements in similar deposits. It appears that a knowledge of the moisture content of the material in its natural state and of the type of fill to be constructed, combined with probe borings to disclose the depth of the muck layer, furnish sufficient information for a rough estimate.

This could be carried out in some such manner as follows:

1. Make sufficient probe borings to determine the thickness of the muck layer.
2. Obtain several samples of the muck for moisture content determination and routine tests, if desired. These samples can be taken during probe boring by driving a pipe smaller than the casing into the soil just below the elevation penetrated by the casing. Samples should be obtained near the middle of the layer.
3. Determine the moisture content of each sample. Use the highest value and assuming that this value represents the moisture content at the liquid limit, determine the compression index, Z, from figure 13. An average value might be used but the highest value is suggested as being on the safe side. If the moisture content of one of several samples varies considerably from the others, it should be discarded.
4. From formula (5) determine value of intercept B. From figure 11 select the load-compression curve nearest the determined values of B and Z. If no curve fits the values closely, or if otherwise desired, the load-compression curve may be plotted since the data are sufficient to fix the position of the curve.
5. Determine the voids ratio corresponding to the natural moisture content, using a specific gravity of 2.6. Determine the equivalent load from the selected load-compression curve. Add the amount of superimposed load to be used, thus obtaining the total load. Read off the ultimate voids ratio from the chosen curve. Compute the maximum settlement.
6. Using values of 0.4 inch for d_1, and known field thickness, D_1, in formula (7), determine the laboratory time interval corresponding to the selected field time intervals. Read the corresponding percentages off of figure 14. Any of the six time-compression curves may be used but it is suggested that all six be considered as a band, and for each time interval the bottom of the band be read since this will give higher percentages and thus any error will be on the side of safety. Determine the settlement for the selected time interval.

The following example will serve to illustrate this short approximate method.

Probe borings disclose that a muck layer about 15 feet thick exists at the site of a proposed fill. The muck rests on a firm sand and is entirely under water. The proposed fill will produce a pressure of 1.5 tons per square foot. The natural moisture content of the muck is found to vary from 100 to 120 percent. Using this latter value, the compression index, Z, of this soil is about 1.33 according to figure 13. From formula (5)

$$B=0.66+Z=0.66+1.33 \text{ or } 1.99.$$

According to figure 11 these values indicate a load-compression curve closely approaching that for core 5 material. Consequently, that curve can be used. Using a natural moisture content of 120 percent, which corresponds to an initial voids ratio e_1, of 3.12, the sample is found to be compressed by an equivalent load of about 0.13 ton per square foot, as read off the curve for core 5 material, figure 11. The total load is thus 1.50+0.13 or 1.63 tons per square foot. According to the curve being used, this load is capable of compressing the muck to a voids ratio, e_2, of about 1.70. The ultimate settlement for an initial thickness, D_1, of 15 feet is

$$\frac{e_1-e_2}{1+e_1}\times D_1=\frac{3.12-1.70}{4.12}\times 15=5.2 \text{ feet.}$$

Substituting in formula (7) for the laboratory time period corresponding to 6 months in the field

$$t_d=6\times 30\times 1{,}440\frac{(.4)^2}{(15\times 12)^2}=\text{about 1.3 minutes.}$$

According to figure 14 the maximum consolidation occurring in any of the Four Mile Run muck samples in the laboratory at 1.3 minutes was about 38 percent. Therefore the estimated settlement likely to occur in 6 months is 38 percent of 5.2 feet, or 2.0 feet. By the same procedure the settlement after 1 year is estimated at about 48 percent or 2.5 feet, and the settlement after 5 years is about 80 percent of the maximum or about 4.2 feet. Similarly the settlement after any desired time can be determined.

The foregoing is not recommended as an accurate method but will give a rough estimate of settlements likely to occur in muck beds similar in character and subjected to loading of the character discussed in this report. In any case, it is desirable to perform the laboratory tests indicated in table 1 and to compare the results with those given in this table, and plotted in figures 3A and 3B. If the soil in question shows a considerable variation from these results, this method should not be employed.

STATUS OF FEDERAL AID HIGHWAY PROJECTS

(1936 FUNDS)

AS OF JANUARY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 52,617	$ 36,918	0.8	$ 1,812,737	$ 1,497,238	100.4	$ 15,723	$ 8,138	0.1	239,053
Arkansas	2,142,723										2,142,723
California	4,756,959	52,448	30,264	1.5	3,279,733	1,888,869	44.5	886,816	505,147	22.2	2,332,679
Colorado	2,288,811	25,046	14,026	.1	1,761,938	986,685	78.0	403,797	226,126	10.1	1,061,974
Connecticut	791,253										791,253
Delaware	609,375							422,476	209,443	38.2	399,932
Florida	1,655,723				674,678	337,339	23.8	218,968	109,484	8.8	1,208,900
Georgia	3,168,221				704,612	346,081	48.4	1,551,665	775,832	90.1	2,046,308
Idaho	1,531,162	305,432	172,421	44.6	978,940	583,705	95.0	454,955	272,245	33.0	502,791
Illinois	5,160,696				2,965,201	1,482,601	59.2	2,985,054	1,492,527	51.1	2,185,568
Indiana	3,087,613	237,057	118,523	6.9	3,221,269	1,606,817	110.3	1,962,072	980,947	51.6	381,326
Iowa	3,231,718	224,362	105,460	57.5	4,043,360	1,905,165	173.8	1,745,899	820,350	74.6	400,743
Kansas	3,317,054	9,038	4,519	5.3	551,929	275,964	113.8	2,546,000	1,273,000	261.8	1,763,571
Kentucky	2,304,143	375,048	187,524	19.7	1,661,657	811,246	111.6	1,306,165	617,178	49.3	688,195
Louisiana	1,776,939				959,642	479,821	35.7	1,175,105	587,552	40.7	709,566
Maine	1,090,167	113,605	56,802	2.1	1,504,065	752,033	49.6	94,663	47,332	1.9	234,000
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877							396,055	198,028	3.1	1,543,849
Michigan	3,837,292	815,500	407,750	25.2	3,315,218	1,654,884	130.4	1,574,450	787,225	66.5	987,433
Minnesota	3,423,306	334,238	143,116	12.2	2,869,146	1,202,522	166.3	1,265,895	472,116	135.5	1,605,552
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,171,810	585,905	220.8	3,127,048	1,563,524	116.0	393,968	196,984	31.6	1,454,443
Montana	2,560,449	691,680	387,272	141.9	938,454	525,440	84.3	1,173,316	656,940	70.5	990,797
Nebraska	2,581,663	1,116,878	558,439	66.5	605,827	302,913	68.2	49,779	44,252	5.2	1,676,059
Nevada	1,595,501	121,853	105,488	55.4	883,442	764,796	95.8				725,217
New Hampshire	609,375				781,661	384,377	20.9	32,264	16,082	1.1	208,916
New Jersey	1,675,751	37,143	18,572	.8	1,424,439	663,995	25.7	1,951,204	975,602	13.9	17,582
New Mexico	1,999,299	67,052	40,731	10.9	1,437,037	880,140	120.1	711,116	432,501	38.9	645,877
New York	6,150,106				7,686,056	3,830,200	143.2	1,997,400	953,250	31.4	1,366,656
North Carolina	2,938,657				1,124,169	561,992	189.6	43,935	21,968	9.0	2,354,697
North Dakota	1,960,162										1,960,162
Ohio	4,565,435				671,412	335,607	7.9	2,776,000	1,387,000	38.4	2,842,828
Oklahoma	2,947,521				1,450,144	762,050	50.4	423,581	220,337	11.6	1,965,134
Oregon	2,044,633				2,181,807	1,316,422	86.5	918,951	560,560	13.0	167,651
Pennsylvania	5,348,062	18,018	9,009	.5	3,971,136	1,985,568	55.9	2,157,858	1,078,592	33.1	2,274,893
Rhode Island	609,375										609,375
South Carolina	1,692,896										1,692,896
South Dakota	2,036,775				516,850	283,389	35.2	67,886	37,222	9.9	1,716,164
Tennessee	2,638,159	43,106	21,553	1.8	874,764	437,382	41.9	439,452	219,726	15.1	1,959,498
Texas	7,777,504	335,741	167,700	19.9	5,741,358	2,849,788	323.0	1,591,479	795,304	84.5	3,964,712
Utah	1,410,752	267,727	193,299	17.0	642,609	453,289	50.0	617,410	379,769	35.4	384,395
Vermont	609,375	25,988	12,994	2.9	1,093,744	546,872	50.8	52,043	26,021	4.7	23,488
Virginia	2,278,475				338,258	169,129	8.5	934,449	467,224	37.2	1,642,122
Washington	1,949,957	637,523	335,800	18.8	1,342,526	705,649	50.6	458,822	241,600	1.4	666,908
West Virginia	1,356,793	87,161	43,581	3.0	490,373	245,186	29.1	211,653	105,826	9.8	962,200
Wisconsin	3,045,557	235,767	117,883	4.8	1,451,933	724,830	71.6	497,253	246,034	14.4	1,956,810
Wyoming	1,559,444	527,052	324,603	83.6	1,968,673	1,212,486	191.0				22,355
District of Columbia											
Hawaii	609,375							229,826	114,641	2.5	494,734
TOTALS	121,875,000	7,928,890	4,200,202	824.5	71,047,845	37,315,994	3,257.0	36,735,403	18,560,105	1,451.2	61,798,699

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JANUARY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 1,296,115	$ 1,296,115	37.1	$ 2,147,050	$ 2,147,050	70.8	$ 707,950
Arizona	2,569,841	$ 84,628	$ 84,628	11.0	1,184,660	1,114,773	67.6	530,314	411,917	28.3	958,522
Arkansas	3,352,061				1,191,239	1,189,621	86.5	847,757	846,294	79.5	1,316,145
California	7,747,928				2,260,950	2,136,474	98.9	2,953,704	2,859,512	95.0	2,751,942
Colorado	3,395,263	20,152	20,152	.7	1,017,393	1,017,002	66.1	309,829	309,829	13.4	2,048,280
Connecticut	1,418,709										1,418,709
Delaware	900,310				181,520	181,520	19.2	314,050	314,050	34.2	404,740
Florida	2,597,144				885,073	867,200	30.9	550,249	550,249	12.1	1,179,695
Georgia	4,988,967				47,181	47,181	.7	426,627	426,627	28.4	4,515,158
Idaho	2,222,747				974,913	953,356	84.0	236,081	200,935	15.3	1,068,456
Illinois	8,694,009				2,525,295	2,525,295	109.3	3,200,524	3,200,524	226.2	2,968,190
Indiana	4,941,255				714,325	714,325	35.2	3,031,947	3,031,947	182.9	1,194,983
Iowa	4,991,664				755,852	721,415	55.7	1,243,423	1,181,899	197.5	3,088,350
Kansas	4,994,975				1,580,386	1,580,386	172.0	947,105	946,105	98.9	2,468,484
Kentucky	3,726,271				699,705	699,705	100.8	1,766,866	1,748,811	201.8	1,277,755
Louisiana	2,890,429							817,186	544,923	36.0	2,345,506
Maine	1,676,799				704,322	704,322	33.4	621,785	621,237	26.3	351,241
Maryland	1,750,738							254,866	254,866	10.5	1,495,872
Massachusetts	3,262,885							115,246	115,246	1.1	3,147,639
Michigan	6,301,414	452,100	452,100	22.2	4,477,221	4,477,221	216.7	1,104,100	1,044,070	41.1	328,023
Minnesota	5,277,145	55,973	55,973	37.5	911,041	837,660	66.4	1,678,837	1,506,273	419.7	2,877,239
Mississippi	3,457,552				1,034,282	1,031,897	59.4	1,129,372	1,129,372	70.0	1,296,283
Missouri	6,012,652	28,173	28,173	14.3	1,758,680	1,758,680	386.4	1,622,254	1,622,254	302.6	2,603,545
Montana	3,676,416				1,959,107	1,959,107	110.8	1,027,895	1,027,895	63.0	689,414
Nebraska	3,870,739				993,968	989,167	102.1	1,263,046	1,230,595	120.3	1,650,977
Nevada	2,243,074	13,570	13,570		1,326,226	1,314,226	54.2	95,609	83,609	1.0	831,668
New Hampshire	945,225				257,318	255,212	7.3	163,250	104,458	4.6	585,555
New Jersey	3,129,805				507,749	507,749	8.5	1,183,286	1,183,286	4.4	1,438,770
New Mexico	2,871,397				986,014	986,014	89.9	554,130	554,130	26.1	1,331,253
New York	11,046,377				4,132,138	4,076,148	32.9	2,094,470	1,908,559	31.2	5,061,670
North Carolina	4,720,173				1,172,225	1,172,225	109.3	527,026	524,055	32.6	3,023,894
North Dakota	2,867,245	140,150	140,150	20.8	328,520	328,520	48.4	98,905	98,905	17.8	2,299,670
Ohio	7,670,815				1,201,932	1,201,932	13.6	1,330,300	1,319,300	11.7	5,149,583
Oklahoma	4,580,670				466,267	466,267	37.7	1,869,249	1,869,249	184.9	2,245,154
Oregon	3,038,642				1,478,728	1,468,728	44.0	752,299	735,034	84.9	834,880
Pennsylvania	9,347,797				149,696	149,696	.1	787,076	787,076	34.0	8,411,025
Rhode Island	989,208				113,368	113,368	4.0	546,895	543,228	11.0	332,612
South Carolina	2,702,012				296,459	296,459	25.2	468,873	468,713	50.3	1,936,840
South Dakota	2,976,454	79,687	79,687	30.1	590,313	590,313	152.3	360,270	360,270	68.4	1,946,184
Tennessee	4,192,460				505,406	505,406	22.6	611,494	611,494	26.1	3,075,560
Texas	11,989,350	8,067	7,769	4.9	4,384,793	4,220,319	392.9	2,831,504	2,790,062	233.5	4,971,201
Utah	2,067,154	27,439	27,439		587,011	566,399	51.6	348,285	318,611	29.6	1,154,705
Vermont	924,306				240,481	235,181	7.2	371,792	347,077	9.3	342,048
Virginia	3,652,667	39,453	39,453	28.9	886,865	886,865	475.6	572,218	572,218	209.7	2,154,132
Washington	3,026,161				1,645,583	1,586,948	81.9	766,611	628,279	51.4	810,934
West Virginia	2,231,412				574,968	574,968	30.3	311,060	311,060	9.1	1,345,383
Wisconsin	4,823,884	60,230	50,000	1.3	1,422,212	1,219,083	61.3	2,094,528	1,953,521	168.2	1,601,280
Wyoming	2,219,155				1,010,633	1,010,628	52.6	672,782	672,774	60.8	535,753
District of Columbia	949,496	238,253	238,253	1.9	525,643	501,613	4.1				209,631
Hawaii	926,033				332,074	318,456	4.3	154,448	151,751	1.6	455,826
TOTALS	195,000,000	1,247,875	1,237,347	173.6	52,275,850	51,355,145	3,751.6	47,706,473	46,169,199	3,737.1	96,238,309

U. S. GOVERNMENT PRINTING OFFICE: 1936

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JANUARY 31,1936

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
				NUMBER				NUMBER				NUMBER		
		Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	Estimated Total Cost	Works Program Funds	Eliminated by Separation or Relocation	Protected By Signals or Otherwise	
Alabama	$ 4,034,617					$ 1,384,174	$ 1,384,174	17		$ 1,954,160	$ 1,954,160	16	1	$ 696,283
Arizona	1,256,099					50,000	50,000	1		623,661	469,908	5		736,191
Arkansas	3,574,060					535,740	534,897	13		730,904	728,256	21		2,310,908
California	7,486,362					3,530,358	3,363,315	22		2,499,737	2,428,900	13		1,694,148
Colorado	2,631,567					902,884	881,588	16		198,051	198,051	2		1,551,927
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					713,695	713,695	6		554,303	554,303	6		1,559,885
Georgia	4,895,949									10,581	10,581			4,885,368
Idaho	1,674,479					542,501	518,887	9		288,974	248,811	3		906,781
Illinois	10,307,184					380,078	380,078	2		2,126,788	2,126,788	32		7,800,318
Indiana	5,111,096					1,671,256	1,671,256	9		1,411,865	1,411,864	8		2,027,976
Iowa	5,600,679					764,388	732,950	12		584,581	557,700	15		4,310,029
Kansas	5,246,258					78,694	78,694			2,242,473	2,242,473	23		2,925,091
Kentucky	3,672,387					165,603	140,290	2		2,438,067	1,910,539	15		1,621,558
Louisiana	3,213,467									1,293,840	1,026,000	13		2,187,467
Maine	1,426,861					141,606	141,272	3		240,550	240,550	4		1,045,038
Maryland	2,061,751									834,595	834,595	6		1,227,155
Massachusetts	4,210,833					756,997	756,997	3		317,872	317,872	1		3,135,965
Michigan	6,765,197					2,907,852	2,907,852	29		2,124,600	2,124,600	11		1,732,745
Minnesota	5,395,441	$ 48,769	$ 48,769	2		482,903	476,853	6		404,216	404,216	11	1	4,465,604
Mississippi	3,241,475					175,124	175,124	4		1,212,094	1,212,094	21		1,854,258
Missouri	6,142,153					232,638	232,638	3		1,237,380	1,237,380	10		4,672,135
Montana	2,722,327					1,441,742	1,441,742	26		495,590	495,590	10		784,995
Nebraska	3,556,441					712,177	712,177	25		1,113,231	1,113,231	30		1,731,033
Nevada	887,260					306,096	306,096	7		13,308	13,308			567,856
New Hampshire	822,484									222,531	222,531			599,953
New Jersey	3,983,826									462,237	462,237	2		3,521,589
New Mexico	1,725,286					316,721	302,895	5		530,164	507,919	4		914,472
New York	13,577,189					3,026,210	2,924,910	8		1,675,070	1,638,070	9		9,014,209
North Carolina	4,823,958					695,648	695,648	6		342,046	342,046	7		3,786,264
North Dakota	3,207,473					147,361	147,361	3		25,875	25,875	1		3,034,236
Ohio	8,439,897					126,598	126,598							8,313,299
Oklahoma	5,004,711					544,435	544,435	10		1,072,935	1,067,935	18		3,392,340
Oregon	2,334,204					778,822	777,061	5		718,416	718,416	5		838,727
Pennsylvania	11,483,613					219,670	203,527	5		1,108,400	1,063,900	18		10,216,186
Rhode Island	699,691					236,879	236,879			457,910	419,691	4		43,121
South Carolina	3,059,956					244,332	244,332	5		641,719	641,719	18		2,173,905
South Dakota	3,249,086					175,596	175,596	4		188,703	188,703	2		2,884,787
Tennessee	3,903,979					78,679	78,679	1		273,217	273,217	5		3,552,083
Texas	10,855,982					376,391	376,391	10		1,897,509	1,888,055	25		8,591,536
Utah	1,230,763					162,902	162,902	1		327,847	268,915	6		798,946
Vermont	729,857					351,069	349,711	4		138,704	138,704	3		241,442
Virginia	3,774,287					228,748	228,748	4		33,994	33,994	2		3,511,545
Washington	3,095,041					1,226,743	1,226,743	13		448,854	444,054	6		1,424,244
West Virginia	2,677,937													2,677,937
Wisconsin	5,022,683					984,727	921,991	10		1,283,987	1,283,987	9		2,816,705
Wyoming	1,360,841					55,366	55,365	2						1,305,476
District of Columbia	410,804									166,697	166,697	2		244,107
Hawaii	453,703									314,873	314,873	3		138,830
TOTALS	196,000,000	48,769	48,769	2		27,855,403	27,380,347	311		37,283,109	35,973,308	425	2	132,597,576

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF JANUARY 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 N.I.R. Act (June 16, 1933) 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,378,133	$ 4,259,043	$ 10,908,465	$ 8,171,070	$ 2,475,607	727.4	$ 1,229,130	$ 186,798	$ 1,042,332	49.2		$ 283,393	2.6	$ 57,264	$ 457,711
Arizona	5,211,760	2,641,776	6,402,449	5,190,476	2,199,301	527.6	411,729	4,927	334,360	17.5		34,734	.8	16,357	74,179
Arkansas	6,748,335	3,428,049	9,968,434	6,527,672	2,497,094	550.1	797,698	78,913	716,663	52.2		59,956	7.9	141,750	154,336
California	15,687,354	7,932,587	27,429,667	15,681,671	6,046,472	750.8	2,873,420		1,722,745	22.7		127,466	.2	5,683	35,904
Colorado	6,874,530	3,486,006	11,135,663	6,831,431	3,450,779	636.4	5,012		5,012			1,847	.1	43,099	28,368
Connecticut	2,865,740	1,454,866	4,142,222	2,825,079	941,105	69.3	359,166		343,645	3.7		58,859	.1	40,661	111,258
Delaware	1,814,088	923,394	2,645,565	1,814,088	775,652	128.3	32,528		32,528						115,214
Florida	5,231,834	2,661,347	8,238,102	5,211,895	1,835,538	281.7	633,343		551,388	25.6		175,525	1.7	19,939	98,892
Georgia	10,041,185	5,113,491	11,777,572	9,042,626	2,240,596	673.9	1,352,281	436,431	867,827	63.3	$ 82,205	770,247	45.7	479,923	1,234,821
Idaho	4,486,249	2,277,487	6,134,386	4,394,175	1,404,598	488.7	695,001		693,751	8.6		111,523	4.1	92,074	67,615
Illinois	17,565,770	8,921,401	20,666,437	15,568,270	4,765,941	580.7	5,483,515	1,920,565	3,562,950	114.1	3,836	338,505		73,098	254,005
Indiana	10,037,843	5,032,963	12,210,015	9,065,834	2,659,860	384.2	2,879,052	791,499	2,052,160	102.2	58,342	136,513	2.2	122,168	184,431
Iowa	10,055,660	5,118,361	15,413,663	9,939,405	4,698,510	1,220.3	297,801	114,154	162,100	4.9		1,000	2.3	2,101	256,751
Kansas	10,089,604	5,117,675	13,857,556	9,969,212	3,504,506	1,069.3	1,630,198	39,153	1,591,045	62.9	48,981	12,798	2.2	32,258	9,326
Kentucky	7,517,359	3,818,311	10,606,867	6,981,045	2,899,293	757.3	1,106,917	432,327	596,043	47.9	55,381	116,214	7.6	48,606	206,761
Louisiana	5,828,591	2,963,932	6,733,393	4,614,872	1,554,537	204.7	2,063,383	1,008,226	1,013,203	38.5	149,287	366,106	17.2	56,206	31,087
Maine	3,369,917	1,711,586	4,912,806	3,343,664	1,373,482	184.8	286,379		286,364	8.3				26,253	51,740
Maryland	3,564,527	1,810,056	4,296,510	2,786,846	600,931	113.3	1,163,202	706,935	450,722	31.3		162,409	4.9	70,745	595,996
Massachusetts	6,597,100	3,350,474	6,861,318	4,587,051	1,687,727	102.9	3,368,874	1,974,333	1,394,541	12.4				35,715	268,206
Michigan	12,736,227	6,452,568	17,999,163	12,544,952	4,468,553	673.1	2,097,802	117,227	1,922,598	95.7		30,825	.1	74,048	30,592
Minnesota	10,656,569	5,425,551	15,382,571	9,883,873	4,786,377	1,623.6	834,658	606,826	188,795	26.2	17,260	185,846	2.0	148,610	264,533
Mississippi	6,978,675	3,540,228	10,238,181	5,952,364	1,628,509	594.2	2,520,004	877,112	1,400,797	126.0	6,059	440,937	26.3	143,140	69,985
Missouri	12,180,306	6,173,740	14,928,766	10,868,487	3,105,538	1,350.1	4,224,185	1,185,562	2,765,861	100.6		248,256	.6	126,257	54,085
Montana	7,419,748	3,769,734	10,980,121	7,160,278	3,156,147	1,001.2	605,546	159,632	445,914	29.7		56,546		99,838	111,127
Nebraska	7,828,961	3,964,364	12,363,117	7,610,645	3,373,278	992.1	732,366	40,701	457,313	42.0		4,289		177,614	129,484
Nevada	4,545,917	2,302,356	6,650,573	4,502,460	1,991,464	735.6	351,978	26,150	289,722	21.7		4,675		17,317	16,494
New Hampshire	1,909,839	969,462	2,941,655	1,909,443	915,231	77.2	30,238		30,238	.5				397	23,993
New Jersey	6,346,039	3,220,879	6,948,192	6,002,237	587,836	74.9	2,636,867	175,941	2,143,993	12.4				167,861	489,050
New Mexico	5,792,935	2,941,700	8,209,865	5,631,430	2,375,529	747.6	439,280		439,280	19.7	114	777		161,391	126,114
New York	22,330,101	11,327,921	37,143,511	21,658,832	9,032,670	802.1	3,244,193	503,800	2,132,799	22.7	75,917	66,200	.9	91,492	96,251
North Carolina	9,522,293	4,840,941	14,019,596	8,813,464	3,989,583	1,322.0	910,370	320,633	572,842	21.6	65,953	212,599	4.3	322,243	65,917
North Dakota	5,804,448	2,938,967	7,308,213	5,510,239	1,151,028	1,949.5	753,940	130,778	564,567	112.3	67,289	537,809	62.1	96,143	685,562
Ohio	15,484,592	7,865,012	22,414,122	15,279,149	5,500,147	747.8	2,084,856	158,521	1,791,106	27.9		364,868	21.6	46,921	208,892
Oklahoma	9,216,798	4,685,180	12,899,467	9,041,780	2,987,813	761.8	1,431,422	153,088	1,276,599	42.5		183,352	1.9	21,931	237,416
Oregon	6,106,896	3,097,814	9,395,813	5,897,458	2,655,189	461.4	427,145	99,557	264,264	4.0		17,837	.8	109,880	160,524
Pennsylvania	18,891,004	9,590,788	27,240,779	17,884,029	8,131,300	982.4	1,597,179	738,565	772,568	76.8	5,126	307,671	2.2	263,284	379,249
Rhode Island	1,998,708	1,014,572	2,958,197	1,998,708	853,971	88.0	138,587		137,102	1.1		880			22,619
South Carolina	5,459,165	2,770,954	6,389,709	5,009,340	1,248,304	495.0	1,428,715	303,208	1,101,298	123.2	15,740	19,503	.2	130,878	401,849
South Dakota	6,011,479	3,047,643	8,528,708	5,779,245	2,200,439	1,471.1	413,519	15,396	398,123	50.3	62,646	299,804	24.2	154,192	149,277
Tennessee	8,492,619	4,302,991	11,966,612	8,182,177	2,915,872	460.9	1,285,310	293,634	895,275	22.9	13,049	185,008	2.0	3,760	306,835
Texas	24,244,024	12,291,253	32,931,119	23,379,310	7,997,100	2,617.8	5,081,355	834,209	4,018,207	157.8	1,537	156,661	16.7	28,969	119,285
Utah	4,194,708	2,132,691	6,912,098	4,156,356	1,862,147	584.0	327,904	6,060	267,191	6.9		1,500		32,291	1,853
Vermont	1,867,573	948,007	3,031,504	1,863,531	849,229	137.6	109,059	3,922	90,873	2.4		2,713		121	5,192
Virginia	7,416,757	3,765,387	11,169,043	7,180,354	3,073,047	568.9	505,354	99,518	398,492	48.7	42,221	46,881	.8	94,664	246,967
Washington	6,115,867	3,106,412	8,843,909	6,101,000	2,527,319	299.5	524,373		518,276	3.3		4,692		14,867	56,125
West Virginia	4,474,134	2,230,335	5,267,827	4,170,093	932,970	182.6	1,259,990	268,494	937,563	35.9	5,987			29,560	409,802
Wisconsin	9,724,881	4,941,837	14,855,100	9,642,681	4,318,541	604.7	572,508	7,300	522,766	15.3		93,112		74,900	7,418
Wyoming	4,501,327	2,287,712	6,537,332	4,433,873	1,923,598	987.8	359,722	46,705	286,281	49.5		47,239		20,744	30,595
District of Columbia	1,918,469	973,842	2,576,427	1,917,978	660,313	19.5	313,125		277,625	2.9				491	35,904
Hawaii	1,871,062	949,778	1,496,428	1,122,101		32.2	1,471,542	748,961	534,135	19.9		169,484	1.1		246,158
TOTALS	334,000,000	200,000,000	560,186,479	373,589,603	138,810,771	32,893.9	65,389,721	15,615,761	45,261,542	1,987.7	776,992	6,502,339	267.4	4,017,644	9,425,348

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 1 MARCH 1936

HIGHWAY BRIDGE OVER THE ST. CROIX RIVER AT STILLWATER, MINNESOTA

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

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BUREAU OF PUBLIC ROADS

Volume 17, No. 1 March 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

THE MINNESOTA FINANCIAL SURVEY

DIGEST OF A SURVEY OF THE FINANCES OF MINNESOTA IN 1932, WITH SPECIAL REFERENCE TO HIGHWAYS, CONDUCTED BY THE BUREAU OF PUBLIC ROADS AND THE UNIVERSITY OF WISCONSIN

Reported by **ELIZABETH CHURCH**, Assistant Research Analyst, Division of Highway Transport, Bureau of Public Roads

THE DEVELOPMENT of highway systems, for the most part, has been a process of evolution. In the past but little information has been gathered concerning the location of roads, the sources of revenue, the places of expenditure, and highway laws—information upon which rational highway planning should be based. With a network of roads laid out and partially improved, the main problems now confronting highway officials are the coordination and improvement of service in accordance with traffic needs and local economic conditions.

This cooperative economic survey is intended to serve as an aid to highway planners. The primary objective of the survey was to determine all facts connected with the financing of roads and streets. This involved the determination of highway revenues, disbursements and debt, the relations of highway receipts and expenditures to all other public financial transactions, the mileage and surfacing of the various systems of roads, and general data concerning the distribution of wealth and population throughout the State.

In Minnesota a road-use study was made in addition to the economic survey. The purpose of this second study was to determine the amount and origin of travel upon the various systems of roads and streets in both rural and urban areas. By correlating the two types of studies a measurement of benefits as compared with expenditures can be made.

The Minnesota financial survey is the fifth of a series of similar investigations conducted in various States. It was carried on under a cooperative agreement between the Bureau of Public Roads, the Minnesota State Highway Department, and the University of Wisconsin.[1]

PLAN OF STUDY OUTLINED

Information was gathered from all units of government within the State. This necessitated the consulting of records, personal visits to State officials and some county and local officials, frequent conferences, and the compilation of data obtained by many thousands of questionnaires. The data so gathered were tabulated, analyzed, and subsequently presented in such form as to facilitate comparisons.

Information is shown for the rural areas and urban places, the latter being grouped according to population in the 1930 census as follows:

Group 1—places having a population under 2,500.

Group 2—places having a population from 2,500 to 14,999.

Group 3—places having a population from 15,000 to 74,999.

Group 4—places having a population from 75,000 to 399,999.

Group 5—places having a population from 400,000 to 999,999. St. Paul and Duluth are the only cities in group 4 and Minneapolis is the only city in group 5.

The data for taxes and receipts are shown by type of impost, and a tabulation showing the source of highway revenues was made. Taxes are also shown by the unit of government responsible for their levy and by the class of place liable for their payment. Expenditures are classified according to the purpose for which they were made—highways, education, public benefit, and government. They are shown both as expended by the several governmental agencies and as expended in and for the rural areas and the various classes of urban places. The outstanding indebtedness is classified by the unit of government incurring it and by the purposes for which originally contracted. Payments for debt service are divided between those made for principal and interest and are shown by the unit of government incurring the costs.

In this summary the general economic facts are presented first to form a background for the detailed discussion of highways and highway usage that follows.

The following definitions are basic in all of the surveys:

Highway refers to the construction, maintenance, and administration of all roads, streets, and alleys. Street cleaning and street lighting are considered items of public benefit and are not included in the definition of highways. Highways are classified as State, county, and rural roads and city streets. These highway classifications are further discussed later in this report.

Education consists of all activities in connection with the construction, maintenance, and administration of and teaching in all public schools. The functions of public libraries are considered to be educational activities.

Public benefit consists of all items pertaining to the protection of lives and property and the pleasure or well-being of the people. It includes police and fire protection, courts, sanitation, parks and playgrounds, and charitable and penal institutions.

Government includes all items concerning the general administration of public affairs not included in the definitions of the three preceding public purposes. These are primarily the executive and administrative functions of government.

Expenditures are public costs defrayed out of public funds. The net expenditures (the total expenditures less the earnings made by the public service charged with the costs) are shown. Interest but not principal payments on indebtedness are included in the definition of expenditures.

Debt service consists of the interest and principal payments on public obligations during the year. The total public disbursements can be obtained by adding debt principal payments to the expenditures. Debt retirement payments are not considered as a cost of the current year. Such practice would result in a duplication of costs, as the funds are considered as an expenditure of the year when borrowed and spent.

Imposts include every payment of any nature made to a public body in connection with the authority vested

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[1] The study was made during 1934 under the immediate direction of Dr. Henry R. Trumbower, professor of economics at the University of Wisconsin and economist for the Bureau of Public Roads, and H. R. Briggs, field investigator and statistician.

Roads on the State Trunk Highway System.

within it. Thus, all licenses, fees, permits, special assessments, and taxes proper are shown as imposts.

User revenues are the imposts paid by the operators of motor vehicles in the form of vehicle license fees, motor-fuel taxes, and miscellaneous motor-vehicle imposts.

The data for Minnesota are shown for the calendar year 1932. In cases where the calendar and fiscal years did not coincide, slight adjustments were made to obtain comparable statistics.

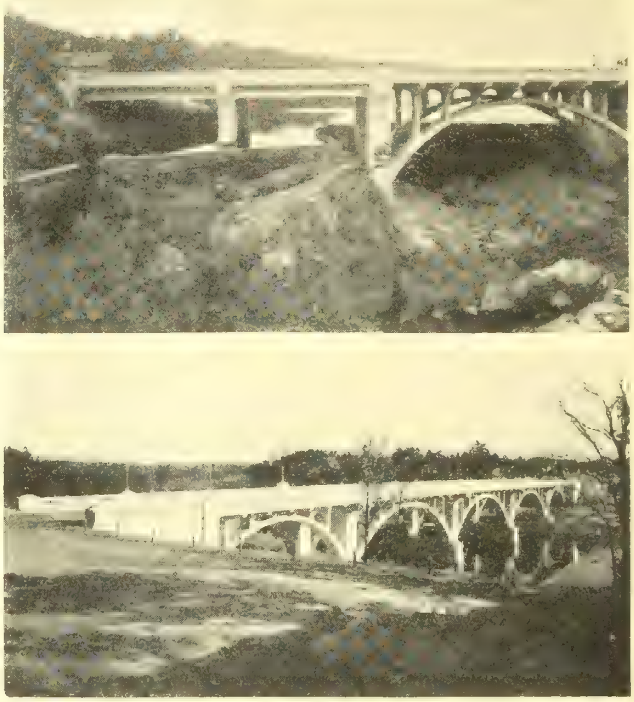
POPULATION AND VALUATION DATA PRESENTED

Minnesota is chiefly a farming State, with almost two-thirds of its total population of 2,563,953 living in rural areas and small incorporated places. All but 3 percent of the remainder of the population live in the three cities of Minneapolis, St. Paul, and Duluth. In Minnesota there are only 13 cities and one village (Hibbing) having populations over 10,000. The population distribution between the various classes of places is shown in table 1.

Table 1.—*Population and assessed valuation of the townships and incorporated places in Minnesota*

Class of place	Population [1]		Valuation [2]		Per capita valuation
	Number of persons	Percent	Amount	Percent	
Townships (rural areas)	966, 819	37. 7	$808, 798, 600	42. 9	$836. 56
Places to 2,499	339, 518	13. 2	192, 788, 800	10. 2	567. 83
Places 2,500 to 14,999	342, 054	13. 3	191, 344, 500	10. 2	559. 40
Places 15,000 to 74,999	78, 137	3. 1	102, 232, 600	5. 4	1, 308. 38
St. Paul and Duluth	373, 069	14. 6	258, 220, 100	13. 7	692. 15
Minneapolis	464, 356	18. 1	330, 853, 600	17. 6	712. 50
State total	2, 563, 953	100. 0	1, 884, 238, 200	100. 0	734. 90

[1] In 1930. [2] In 1932.



Highway Bridges in Minnesota: Upper, Bridge Over Redwood River at Redwood Falls; Lower, Bridge Over Mississippi River at Brainerd.

The total assessed valuation of Minnesota in 1932 was $1,884,238,200, of which 42.9 percent was in the rural areas. The distribution between the various classes of places is shown in table 1. Hennepin, Ramsey, and St. Louis counties, assessed at more than 45 percent of the total valuation of the State, embody only 9 percent of the area. The assessed value of 29 counties comprising over 45 percent of the area of the State is only 12 percent of the total valuation.

The per-capita valuation ranges from $559 in the places having a population from 2,500 to 14,999 to $1,308 in the places having a population from 15,000 to 74,999. The high per-capita valuation in the latter group is caused by the inclusion of the village of Hibbing, where mining property located within the corporate limits raises the per-capita valuation to $4,494.

GENERAL PROPERTY TAX PRINCIPAL SOURCE OF REVENUE

In Minnesota, as in most other States, the principal source of revenue is the general property tax, which yielded $127,496,900 in 1932. This amount is 75.1 percent of the total tax levy for that year. Considered as levies on general property and therefore included in the above total are $8,371,300 of special assessments which are levied by the local units of government (table 2).

The State levied $14,856,000, or 11.7 percent of the total general property tax; the counties levied $24,977,700, or 19.6 percent; and the urban and rural local units of government levied $87,663,200, or 68.7 percent.

Of second importance as sources of revenue are the State motor-vehicle imposts. In 1932 the motor-vehicle owners contributed $20,368,100 of user revenues. This amount was 12 percent of the total imposts received. The other sources of revenue are also shown in table 2.

MINNESOTA TAXES IN 1932

Total taxes and imposts levied for all purposes in Minnesota in 1932 were $169,742,600. Taxation of general property totaled $127,496,900; all motor-vehicle imposts, including motor-fuel tax, $20,368,100; other taxes including insurance and inheritance taxes, money and credits tax, railroad taxes, and miscellaneous State and local revenues, $21,877,600.

Of the total taxes and imposts levied, rural taxpayers were charged with $51,497,100, or 30.3 percent; residents of incorporated places having a population to 2,499, $21,780,800 or 12.8 percent; in places of 2,500 to 14,999 population, $23,430,800 or 13.8 percent; in places of 15,000 to 74,999 population, $8,942,300 or 5.3 percent; in St. Paul and Duluth, $27,486,500 or 16.2 percent; and in Minneapolis, $36,605,100 or 21.6 percent.

The average actual tax rates on general property per $100 valuation were as follows: Rural, $4.88; incorporated places to 2,499 in population, $8.00; places of 2,500 to 14,999 population, $8.97; places of 15,000 to 74,999 population, $6.71; St. Paul and Duluth, $8.16; and Minneapolis, $8.33.

Rural motor-vehicle owners paid in license fees and gasoline taxes an average of $21.87; those resident in incorporated places to 2,499 population, $27.36; in places 2,500 to 14,999 population, $29.95; in places 15,000 to 74,999 population, $34.36; in St. Paul and Duluth, $36.05; and in Minneapolis, $36.72.

Table 3 shows the units of government responsible for the levy of the taxes listed in the preceding table. The State government itself levied almost one-third of the total taxes. The counties for their purposes levied about half as much as did the State. The total county tax levy was $25,966,700, or $10.13 per capita. The remainder of the imposts, amounting to $90,791,600, or $35.41 per capita, were levied by the local units of government for their own purposes.

PER-CAPITA TAXATION HIGHEST IN CITIES

All State and county imposts are ultimately paid by taxpayers in the local communities. Table 4 shows the final incidence of taxes by type of tax and by class of place charged with the payment. By deducting the per-capita tax levied by the several classes of local units as shown in table 3 from the per-capita tax paid by these same residents (table 4), the per-capita State and county taxes which the residents in the respective places must pay can be found.

Table 5 presents data that facilitate interesting comparisons. The first column of figures shows the actual tax rates per $100 of valuation as levied on general property in the several classes of places. The second column of figures gives the actual rates needed to raise all funds by general property tax levies. The last column in the table gives the percentages that general property taxes were of the total tax levies, and shows that, had general property been subject to pay all taxes, the rates would have been from 30 to 40 percent higher.

The taxes imposed for street and highway purposes will be shown in more detail later.

HIGHWAY EXPENDITURES AMOUNT TO $21.74 PER CAPITA

In 1932, $175,488,500 was spent by the State, counties, and local units of government to support the varied activities carried on for the residents of Minnesota. The State itself spent $53,582,800, or 30.5 percent of the total and the counties spent $29,708,100, or 16.9 percent. The remainder, $92,197,600, was expended by the rural and urban areas for maintaining the functions of the local governments.

Of the total amount expended by the State, $32,149,900 was for highways, $5,902,800 for education, $13,774,000 for public benefit, and $1,756,100 for government. It is evident from these figures that the main functions of the State, as measured by expenditures, are the construction and maintenance of highways and the protection of persons and property.

TABLE 2.—*Sources of revenue by type of tax or revenue in 1932*

Type of revenue	Amount	Percent	Per capita
Ad valorem general property taxes	$119, 125, 600	70. 2	$46. 46
Special assessments	8, 371, 300	4. 9	3. 26
Telephone and telegraph taxes	898, 100	. 5	. 35
State motor-vehicle imposts	20, 368, 100	12. 0	7. 94
Money and credits tax	1, 257, 400	. 8	. 49
Other local imposts [1]	4, 117, 400	2. 4	1. 61
Inheritance taxes	2, 607, 900	1. 6	1. 02
Insurance taxes	1, 928, 800	1. 1	. 75
Railroad taxes	4, 304, 400	2. 5	1. 68
Miscellaneous State revenue	6, 763, 600	4. 0	2. 64
Total	169, 742, 600	100. 0	66. 20
RECAPITULATION			
General property taxes	$119, 125, 600	70. 2	$46. 46
Special assessments	8, 371, 300	4. 9	3. 26
Motor-vehicle imposts	20, 368, 100	12. 0	7. 94
Other local imposts [1]	4, 117, 400	2. 4	1. 61
Other State receipts	17, 760, 200	10. 5	6. 93
Total	169, 742, 600	100. 0	66. 20

[1] Includes county, township, city, and village fees, fines, licenses, etc.

TABLE 3.—*Total of all State and local charges imposed by the State and its subdivisions for collection in 1932*

Unit of government imposing tax	Amount	Percent	Per capita
State	$52, 984, 300	31. 2	$20. 66
Counties	25, 966, 700	15. 3	10. 13
Townships	20, 794, 400	12. 2	21. 51
Places to 2,499	11, 881, 900	7. 0	35. 00
Places 2,500 to 14,999	14, 291, 700	8. 4	41. 78
Places 15,000 to 74,999	4, 848, 100	2. 9	62. 05
St. Paul and Duluth	15, 876, 800	9. 4	42. 56
Minneapolis	23, 098, 700	13. 6	49. 74
Total	169, 742, 600	100. 0	66. 20

TABLE 4.—*Total of all State and local charges payable by taxpayers in the local units of government in 1932*

Paid by taxpayers in—	General property tax	Motor vehicle and motor fuel taxes [1]	Other taxes	All taxes	Percent	Per capita
Townships	$39, 448, 100	$6, 289, 100	$5, 759, 900	$51, 497, 100	30. 3	$53. 26
Places to 2,499	15, 419, 200	3, 168, 900	3, 192, 700	21, 780, 800	12. 8	64. 15
Places 2,500 to 14,999	17, 164, 600	2, 532, 600	3, 733, 600	23, 430, 800	13. 8	68. 50
Places 15,000 to 74,999	6, 857, 900	680, 000	1, 404, 400	8, 942, 300	5. 3	114. 14
St. Paul and Duluth	21, 058, 900	3, 131, 400	3, 296, 200	27, 486, 500	16. 2	73. 68
Minneapolis	27, 548, 200	4, 566, 100	4, 490, 800	36, 605, 100	21. 6	78. 83
Total	127, 496, 900	20, 368, 100	21, 877, 600	169, 742, 600	100. 0	66. 20

[1] Includes $32,700 out-of-State registration fees.

An Improved Roadside in Minnesota.

Table 5.—*Comparison between the tax rate on general property necessary to produce all revenues from property taxes and the actual tax rate on general property as levied, per $100 valuation*

Unit of government	Actual tax rate on general property as levied	Tax rate needed to raise all funds by general property tax levies	Percentage that general property taxes are of all taxes and imposts
Townships	$4.88	$6.37	76.6
Places to 2,499	8.00	11.30	70.8
Places 2,500 to 14,999	8.97	12.25	73.2
Places 15,000 to 74,999	6.71	8.75	76.7
St. Paul and Duluth	8.16	10.64	76.7
Minneapolis	8.33	11.06	75.3
Average for State	6.77	9.01	75.1

Of the total county expenditures of $29,708,100, $24,452,900, or 82.3 percent, was for highways and public benefit. Only a relatively small amount was spent for education by the counties.

The local rural and urban areas expended 11.8 percent of their money for highways, 56.5 percent for education, 26.3 percent for public benefit, and but 5.4 percent for government (table 6).

Comparisons between the amounts spent by the various governmental units for the several purposes are more obvious when expressed in expenditures per capita (table 7). Since the amount spent for a given purpose is an indication of the extent to which a unit of government performs that service for residents, a comparison of the functions of the several governments can also be made from the tables.

From table 8 it can be seen that the amount spent for education in Minnesota was 33.2 percent of the total expenditures, for highways 31.8, for public benefit 28.3, and for government 6.7.

Sixty percent of the expenditures made by the State government was for highways. This was 57.7 percent of the total amount spent for roads and streets in the entire State. This large expenditure is to be expected, for although the mileage of roads administered by the State is comparatively small, the high types of construction and high standards of maintenance require extensive outlays.

Table 6.—*Total expenditures in Minnesota in 1932 by purpose and by governmental unit*

Purpose	State		County		Local		Total	
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Highways:								
Amount	$32,149,900	60.0	$12,720,700	42.8	$10,862,000	11.8	$55,732,600	31.8
Percent	57.7		22.8		19.5		100.0	
Per capita	$12.54		$4.96		$4.24		$21.74	
Education:								
Amount	$5,902,800	11.0	$301,600	1.0	$52,072,100	56.5	$58,276,500	33.2
Percent	10.1		0.5		89.4		100.0	
Per capita	$2.30		$0.12		$20.31		$22.73	
Public benefit:								
Amount	$13,774,000	25.7	$11,732,200	39.5	$24,246,200	26.3	$49,752,400	28.3
Percent	27.7		23.6		48.7		100.0	
Per capita	$5.37		$4.57		$9.46		$19.40	
Government:								
Amount	$1,756,100	3.3	$4,953,600	16.7	$5,017,300	5.4	$11,727,000	6.7
Percent	15.0		42.2		42.8		100.0	
Per capita	$0.69		$1.93		$1.95		$4.57	
Total:								
Amount	$53,582,800	100.0	$29,708,100	100.0	$92,197,600	100.0	$175,488,500	100.0
Percent	30.5		16.9		52.6		100.0	
Per capita	$20.90		$11.58		$35.96		$68.44	

Table 7.—*All State and local expenditures in 1932, and per capita expenditures by purpose, based on the population in 1930*

Expended by—	Total amount	Per capita expenditure for—				
		Highways	Education	Public benefit	Government	Total
State	$53,582,800	$12.54	$2.30	$5.37	$0.69	$20.90
Counties	29,708,100	4.96	.12	4.57	1.93	11.58
Townships	14,581,000	4.03	9.66	.44	.95	15.08
Places to 2,499	15,859,100	2.54	35.39	6.60	2.18	46.71
Places 2,500 to 14,999	17,288,200	3.74	32,92	11.39	2.49	50.54
Places 15,000 to 74,999	5,030,000	6.22	34.22	19.96	3.98	64.38
St. Paul and Duluth	14,743,900	4.61	19.14	11.33	4.44	39.52
Minneapolis	24,695,400	5.65	20.76	25.63	1.15	53.19
Total	175,488,500	21.74	22.73	19.40	4.57	68.44

Table 8.—*Classification of expenditures by purpose and by units of government in 1932*

Unit of government	Percentage of expenditures by the units of government for the purposes indicated					Percentage of the total expenditure for each purpose made by each unit of government				
	Highways	Education	Public benefit	Government	All purposes	Highways	Education	Public benefit	Government	All purposes
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
State	60.0	11.0	25.7	3.3	100.0	57.7	10.1	27.7	15.0	30.5
Counties	42.8	1.0	39.5	16.7	100.0	22.8	.5	23.6	42.2	16.9
Townships	26.7	64.1	2.9	6.3	100.0	7.0	16.0	.9	7.8	8.3
Places to 2,499	5.4	75.8	14.1	4.7	100.0	1.5	20.6	4.5	6.3	9.0
Places 2,500 to 14,999	7.4	65.1	22.6	4.9	100.0	2.3	19.3	7.8	7.3	9.9
Places 15,000 to 74,999	9.7	53.1	31.0	6.2	100.0	.9	4.6	3.1	2.7	2.9
St. Paul and Duluth	11.7	48.4	28.7	11.2	100.0	3.1	12.3	8.5	14.1	8.4
Minneapolis	10.6	39.0	48.2	2.2	100.0	4.7	16.6	23.9	4.6	14.1
Total	31.8	33.2	28.3	6.7	100.0	100.0	100.0	100.0	100.0	100.0

About 26 percent of the State expenditure was for public benefit. The largest part of this cost was for relief purposes and for the maintenance of charitable and penal institutions. The amount spent by the State for the protection and care of persons and property was 27.7 percent of the total expended for public benefit.

The chief functions of the counties, too, are the construction and maintenance of highways and the protection and care of the people. The State and counties together spent 80.5 percent of the total expenditures made in Minnesota for highways and 51.3 percent of the total for public benefit.

The proportion of county expenditures for government to those for other purposes was relatively high, and represented 42.2 percent of the total expenditures for governmental purposes made by all units of government. This resulted from the large expenditures incurred in connection with the collection and administration of taxes and interest payments on bonds.

The greatest proportion of expenditures by the local units of government was for education. Of the total expenditure of $35.96 per person, $20.31, or 56 percent, was for education. Minneapolis is the only place where the expenditure for education is not the largest single item; the amount spent for public benefit in Minneapolis exceeded by $4.87 per capita the amount spent for education.

In the rural areas a relatively small amount was spent for public benefit. Except for St. Paul and Duluth, the per-capita expenditure for public benefit tended to increase as the size of place increased.

Expenditures by the State and counties are made in and for the benefit of the residents in the rural areas and the several classes of urban places. For example, the total amount spent in the rural areas for all purposes by the State, counties, and townships was $69,160,200, or 39.4 percent of the total of all expenditures. This was $71.53 per capita, of which the townships themselves spent $15.08 per capita. Nearly two-thirds of the amount spent in the rural areas was for highways.

It is not to be inferred, however, that this highway expenditure in rural areas confers an undue benefit upon those localities, as these expenditures were primarily for through highways traveled by vehicles from all parts of the State.

Table 9 shows the entire amount per capita spent in each class of place by all governmental agencies for all purposes.

Table 9.—*Per-capita expenditures by purpose in the several classes of places, based on the population in 1930*

Class of place in which expenditure was made	Highways	Education	Public benefit	Government	Total
Townships	$46.05	$12.10	$9.91	$3.47	$71.53
Places to 2,499	10.07	37.84	15.92	4.70	68.53
Places 2,500 to 14,999	8.21	35.36	21.28	4.99	69.84
Places 15,000 to 74,999	6.88	36.64	29.70	6.23	79.45
St. Paul and Duluth	4.89	21.52	23.93	9.13	59.47
Minneapolis	5.65	23.12	34.97	2.54	66.28
Total	21.74	22.73	19.40	4.57	68.44

Table 10.—*Per-capita taxation and expenditures in 1932, based on the population in 1930*

Class of place	Per-capita taxation	Per-capita expenditures	Ratio of expenditures to taxation
Townships	$53.26	$71.53	1.34
Places to 2,499	64.15	68.53	1.07
Places 2,500 to 14,999	68.50	69.84	1.02
Places 15,000 to 74,999	114.44	79.45	.69
St. Paul and Duluth	73.68	59.47	.81
Minneapolis	78.83	66.28	.84
Average for State	66.20	68.44	1.03

PER-CAPITA EXPENDITURES IN RURAL AREAS EXCEEDED PER-CAPITA TAXATION

A comparison of the taxes and expenditures per capita in the various localities is given in table 10. The taxes are those paid by residents of the communities; the expenditures are those made in and for the residents of the localities by all units of government. The table indicates that there is a flow of funds to the rural areas and smaller urban places. The per-capita expenditures in the rural areas exceeded the per-capita taxation by $18.27. On the other hand the expenditures in the larger urban areas were less than the taxes.

The expenditures for the entire State exceeded the taxation by $2.24 per capita. This lag of taxes behind expenditures reflects the effect of financing current costs from borrowings and balances.

Comprehensive figures regarding the flow of funds from urban to rural communities are given in tables 11, 12, and 13. These tables show that $69,160,200 was expended in the rural areas by all governmental agencies for all purposes, while the same communities paid $51,497,100 in taxes. Of the total expenditures in the rural areas, 21.1 percent was made by the townships and 78.9 percent by the State and counties. This flow of funds to the rural areas is due mainly to the large

TABLE 11.—*Total of all taxes paid by residents of rural and urban areas*

Area	Type of impost	Tax-levying agency								
		Local governments			State and county governments			All governments		
		Amount	Percent	Per capita	Amount	Percent	Per capita	Amount	Percent	Per capita
Rural	Property imposts	$20,731,700	99.2	$21.44	$18,716,400	61.2	$19.36	$39,448,100	76.6	$40.80
	Other imposts	172,500	.8	.18	11,876,500	38.8	12.28	12,049,000	23.4	12.46
	All imposts	20,904,200	100.0	21.62	30,592,900	100.0	31.64	51,497,100	100.0	53.26
Urban	Property imposts	66,931,500	94.1	41.91	21,117,300	44.8	13.22	88,048,800	74.5	55.13
	Other imposts	4,213,300	5.9	2.64	25,983,400	55.2	16.27	30,196,700	25.5	18.91
	All imposts	71,144,800	100.0	44.55	47,100,700	100.0	29.49	118,245,500	100.0	74.04
Total	Property imposts	87,663,200	95.2	34.19	39,833,700	51.3	15.54	127,496,900	75.1	49.73
	Other imposts	4,385,800	4.8	1.71	37,859,900	48.7	14.76	42,245,700	24.9	16.47
	All imposts	92,049,000	100.0	35.90	77,693,600	100.0	30.30	169,742,600	100.0	66.20

TABLE 12.—*Total expenditures by purpose as made by all units of government for residents of rural and urban areas*

Area	Purpose	Local governments			State and county governments			All governments		
		Amount	Percent	Per capita	Amount	Percent	Per capita	Amount	Percent	Per capita
Rural	Highways	$3,894,300	26.7	$4.03	$40,628,800	74.4	$42.02	$44,523,100	64.4	$46.05
	Education	9,342,900	64.1	9.66	2,361,800	4.3	2.44	11,704,700	16.9	12.10
	Public benefit	424,900	2.9	.44	9,155,000	16.8	9.47	9,579,900	13.9	9.91
	Government	918,900	6.3	.95	2,433,600	4.5	2.52	3,352,500	4.8	3.47
	Total	14,581,000	100.0	15.08	54,579,200	100.0	56.45	69,160,200	100.0	71.53
Urban	Highways	6,967,700	9.0	4.36	4,241,800	14.8	2.66	11,209,500	10.5	7.02
	Education	42,729,200	55.0	26.75	3,842,600	13.4	2.41	46,571,800	43.8	29.16
	Public benefit	23,821,300	30.7	14.92	16,351,200	56.9	10.23	40,172,500	37.8	25.15
	Government	4,098,400	5.3	2.57	4,276,100	14.9	2.68	8,374,500	7.9	5.25
	Total	77,616,600	100.0	48.60	28,711,700	100.0	17.98	106,328,300	100.0	66.58
Total	Highways	10,862,000	11.8	4.24	44,870,600	53.9	17.50	55,732,600	31.7	21.74
	Education	52,072,100	56.5	20.31	6,204,400	7.4	2.42	58,276,500	33.2	22.73
	Public benefit	24,246,200	26.3	9.46	25,506,200	30.6	9.94	49,752,400	28.4	19.40
	Government	5,017,300	5.4	1.95	6,709,700	8.1	2.62	11,727,000	6.7	4.57
	Total	92,197,600	100.0	35.96	83,290,900	100.0	32.48	175,488,500	100.0	68.44

TABLE 13.—*Highway taxes paid by residents of rural and urban areas* [1]

Area	Type of impost	Tax-levying agency								
		Local governments			State and county governments			All governments		
		Amount	Percent	Per capita	Amount	Percent	Per capita	Amount	Percent	Per capita
Rural	Property imposts	$5,562,700	100.0	$5.75	$5,028,200	44.5	$5.20	$10,590,900	62.8	$10.95
	Other imposts	..	......	....	6,276,000	55.5	6.50	6,276,000	37.2	6.50
	All imposts	5,562,700	100.0	5.75	11,304,200	100.0	11.70	16,866,900	100.0	17.45
Urban	Property imposts	4,110,100	100.0	2.57	4,613,000	24.7	2.89	8,723,100	38.3	5.46
	Other imposts	.....	.....	....	14,059,400	75.3	8.80	14,059,400	61.7	8.80
	All imposts	4,110,100	100.0	2.57	18,672,400	100.0	11.69	22,782,500	100.0	14.26
Total	Property imposts	9,672,800	100.0	3.77	9,641,200	32.2	3.76	19,314,000	48.7	7.53
	Other imposts	...	....	......	20,335,400	67.8	7.93	20,335,400	51.3	7.93
	All imposts	9,672,800	100.0	3.77	29,976,600	100.0	11.69	39,649,400	100.0	15.46

[1] Does not include $32,700 out-of-State registration fees.

expenditures for highway purposes. This does not mean that subsidies are being granted to rural areas. The residents of urban areas perform travel on these rural roads approximately commensurate with their contributions.

Table 13, which classifies highway taxes, is of particular interest. It shows: (1) That the only taxes levied for highways by the local governments were property imposts; (2) that the property taxes accounted for one-third of the levies made for highways by the State and counties; (3) that of the imposts used for roads and streets, about one-half is from other-than-property taxes, mainly motor-vehicle revenues; (4) that the per-capita property taxes levied for highways in the rural areas were more than twice those levied in the urban areas; and (5) that the property taxes for highways were almost two-thirds of the total highway taxes paid by rural residents, while in the urban areas they represented but a little over one-third of the total paid by urban residents.

INDEBTEDNESS IN MINNESOTA DISCUSSED

The total outstanding indebtedness of all units of government in Minnesota in 1932 was $334,597,800. This consisted of $321,580,700 of bonded debt and $13,017,100 of temporary obligations. Table 14 gives the data for bonded debt only.

The bonded indebtedness of the State government was $111,335,300, of which rural credit bonds of over $60,000,000 comprised the greater portion. These rural credit bonds were agricultural loans intended as advances during an emergency. The State guaranteed their payment, and as the interest is in default upon this debt it has become a State liability. The debt of the State government itself was 34.6 percent of the total for all units of government.

The county bonded debt was $45,890,600, of which over $24,000,000 was for drainage ditches. The counties had no indebtedness for education.

The indebtedness of the townships, villages, and cities was $164,354,800, or 51.1 percent of the total bonded debt. The cities of Minneapolis, St. Paul, and Duluth incurred $109,523,200, or 66.6 percent of this total. The townships or rural areas incurred only $7,346,100, or 4.5 percent, and the municipalities of less than 75,000 population incurred $47,485,500, or 28.9 percent of the total local rural and urban bonded debt.

MINNESOTA EXPENDITURES IN 1932

The total expenditures for all purposes (exclusive of principal payments on bonds and loans) by all units of government in 1932 were $175,488,500, of which $55,732,600 was expended for highways and streets, $58,276,500 for education, $49,752,400 for public benefit, and $11,727,000 for other governmental purposes.

Expenditures by the State were $53,582,800; by the counties, $29,708,100; by Minneapolis, St. Paul, and Duluth, $39,439,300; by other incorporated places, $38,177,300; and by the townships, $14,581,000.

Of the total expenditures, 39.4 percent was made in the rural areas (townships); 13.3 percent in incorporated places having a population to 2,499; 13.6 percent in places of 2,500 to 14,999 population; 3.5 percent in places of 15,000 to 74,999 population; 12.7 percent in St. Paul and Duluth; and 17.5 percent in Minneapolis.

Table 14.—*Total bonded indebtedness of various units of government by purpose in 1932*

Unit of government	Highways	Education	Public benefit	Government	Total
State:					
Amount	$42,759,200	$772,500	$66,476,800	$1,326,800	$111,335,300
Per capita	16.67	0.30	25.93	0.52	43.42
Counties:					
Amount	16,430,100		26,176,500	3,284,000	45,890,600
Per capita	6.41		10.21	1.28	17.90
Townships:					
Amount	1,233,300	5,695,900	81,700	335,200	7,346,100
Per capita	1.28	5.89	0.08	0.35	7.60
Places to 2,499:					
Amount	1,625,900	13,755,400	4,124,100	2,240,800	21,746,200
Per capita	4.79	40.51	12.15	6.60	64.05
Places 2,500 to 14,999:					
Amount	2,878,100	10,982,200	5,342,600	2,349,300	21,552,200
Per capita	8.41	32.11	15.62	6.87	63.01
Places 15,000 to 74,999:					
Amount	84,000	915,000	573,400	2,614,700	4,187,100
Per capita	1.08	11.71	7.34	33.46	53.59
St. Paul and Duluth:					
Amount	11,337,100	14,271,500	20,895,600	3,611,400	50,115,600
Per capita	30.39	38.25	56.01	9.68	134.33
Minneapolis:					
Amount	18,704,200	22,947,000	7,328,600	10,427,800	59,407,600
Per capita	40.28	49.42	15.78	22.46	127.94
Total:					
Amount	95,051,900	69,339,500	130,999,300	26,190,000	321,580,700
Per capita	37.07	27.04	51.09	10.22	125.42

Of the total debt of $95,051,900 outstanding for highways, 62.3 percent was contracted by the State and counties for use on trunk and other main highway routes.

The indebtedness outstanding for public benefit was the largest amount incurred for any one purpose. Of the total debt of $130,999,300 incurred for public benefit, the State and counties contracted $92,653,300, or 70.7 percent. Large issues of rural credit and drainage ditch bonds account for approximately 90 percent of the public benefit debt incurred by the State and counties.

Indebtedness for education totaled $69,339,500, most of which was incurred by the local units of government. The debt for governmental purposes amounted to only 8 percent of the total.

Debt service consists of interest and principal payments on indebtedness. Interest payments are included in the total expenditures, principal payments are not. The total debt service in 1932 was $35,732,800, of which $20,304,400 was for principal and $15,428,400 for interest (table 15). Over 20 percent of the total revenues of all the governmental units in 1932 was used for interest and debt-retirement payments.

Table 15.—*Payments for debt service in 1932*

Unit of government	Principal	Interest	Total
State:			
Amount	$3,969,400	$4,648,100	$8,617,500
Per capita	1.55	1.81	3.36
Counties:			
Amount	3,776,800	2,580,300	6,357,100
Per capita	1.47	1.01	2.48
Local: [1]			
Amount	12,558,200	8,200,000	20,758,200
Per capita	4.90	3.20	8.10
Total:			
Amount	20,304,400	15,428,400	35,732,800
Per capita	7.92	6.02	13.94

[1] Townships and incorporated places.

MINNESOTA HIGHWAY SYSTEM DESCRIBED

There are four main classes of highways in Minnesota: (1) The State trunk system, which includes the Federal-aid system; (2) county roads; (3) local rural roads; and (4) city and village streets.

The routes included in the State trunk system are designated and described in the State constitution and are identical with the numbered State routes. The entire construction and maintenance costs of the trunk routes are met with funds available to the State, and these State roads are entirely under the administration of the State highway department.

County roads are of three classes: (1) The legally designated State-aid roads; (2) county-aid roads; and (3) in some counties, special county roads. All are administered by the county, although some of the support for the State-aid roads comes from the State.

Local rural roads are those roads other than State and county highways lying outside corporate limits. They are administered and entirely financed by the townships.

Urban streets are thoroughfares within corporate units. They are administered by municipal authorities and the funds for their support are derived from local sources. For the most part the State trunk roads lying within the corporate limits are financed and administered by the cities in the same manner as in the case of all urban streets. This is particularly true of the larger cities. The city expenditures, therefore, include amounts spent by municipalities, both on the streets primarily carrying local traffic and also on those streets within the corporate limits that form part of the State routes.

The total mileage of the roads and streets comprising a transportation system must be known in making a complete highway analysis. Except in a few States, however, there is a general lack of adequate and reliable data on this subject. In Minnesota no information is available concerning the mileage of city streets, and the accuracy of the figures for rural highways is questionable.

One of the primary difficulties connected with the problem is the lack of uniformity regarding the meaning of the term "road." Roads may vary from strips of land to which the public has a title for highway purposes to highways open and available to vehicular traffic the year round. Because of the presence in northern Minnesota of so many roads that have legal status but are not actually utilized, field measurements might show the total mileage annually suitable for ordinary vehicular traffic to be as much as 5 percent below the totals that have been compiled.

Table 16 presents information on the mileages, by types, for rural highways. In 1933, 4,500 miles of highway were added to the State trunk system by legislative act, thus making a total of 11,272 miles of trunk routes now under the administration of the State highway department.

Table 16.—*Mileage and degree of improvement of rural highways in 1932*

System	Bituminous concrete and portland cement concrete		Bituminous-treated surface		Gravel		Earth		Total		Percentage of total
	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent	
State	2,407	35.5	2,460	36.3	1,839	27.2	66	1.0	6,772	100.0	6.1
County	115	.4	890	2.8	22,269	69.3	8,852	27.5	32,126	100.0	28.8
Township	2	(1)	21	(1)	22,624	31.2	49,930	68.8	72,577	100.0	65.1
Total	2,524	2.3	3,371	3.0	46,732	41.9	58,848	52.8	111,475	100.0	100.0

[1] Less than 0.1 percent.

HIGHWAY FUNDS OBTAINED FROM SEVERAL SOURCES

The construction and maintenance of roads and streets in Minnesota are financed from the proceeds of property taxes, motor-vehicle imposts, Federal-aid apportionments, and temporary and long-term borrowings. Federal funds in 1932 amounted to $4,457,200, of which $3,039,600 was regular Federal aid and $1,417,600 was from emergency appropriations.

Table 17 shows that, of the taxes used for highways in 1932, 48.7 percent came from the general property tax and 51.3 percent from motor-vehicle revenues. All of the special assessments were made by the local units of government.

The State property tax for highway purposes is a 1-mill levy, the proceeds of which are allocated to the counties for use upon State-aid roads.

The funds for the local township roads and the streets in villages and cities were derived from local sources entirely from levies against property. In the urban communities there were three general types of property imposts used for street purposes: (1) Special assessments; (2) property taxes levied specifically for highway purposes; and (3) property taxes levied for general fund purposes. The proceeds from this last type of levy were not specifically designated as highway taxes, but highway costs were met out of them.

Motor-vehicle registration fees.—Minnesota is one of the few States that tax motor vehicles on the basis of valuation. Vehicles for which this tax is paid are exempt from the regular tax on personal property. Unregistered vehicles in the hands of dealers are subject to the personal property tax, however.

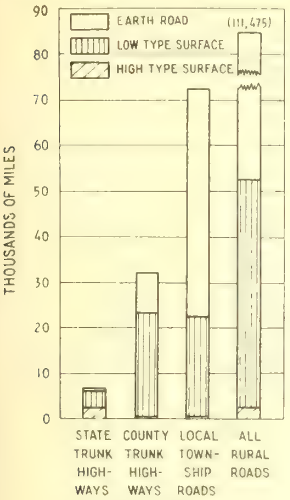
Table 17.—*Taxation imposed for street and highway purposes in 1932*

Type of tax	Amount	Percentage of subtotal	Percentage of total	Per capita
On general property by—				
State	$1,884,200	9.7	4.7	$0.73
County	7,757,000	40.2	19.6	3.03
Local	6,619,900	34.3	16.7	2.58
Special assessments	3,052,900	15.8	7.7	1.19
Total property taxes	19,314,000	100.0	48.7	7.53
On motor vehicles as				
Registration fees [1]	10,019,600	49.2	25.2	3.91
Fuel taxes	10,000,600	49.1	25.2	3.90
Other fees	347,900	1.7	.9	.14
Total motor-vehicle fees	20,368,100	100.0	51.3	7.95
Grand total	39,682,100	.....	100.0	15.48

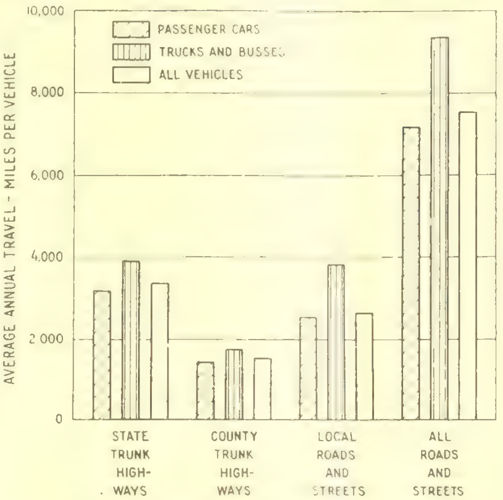
[1] Includes $32,700 nonresident fees.

A total of $10,019,600 in registration fees was collected in 1932. Minnesota residents paid $9,986,900 of this amount and out-of-State residents contributed $32,700. The cost of collecting the registration fees was $367,000 or 3.7 percent of the total gross receipts. This was 52 cents per vehicle registered. The withdrawal from the highway fund was $420,000 for this cost. Of the total proceeds, $2,418,900 was committed to retire trunk highway bonds and to pay the interest on this debt. Only $7,180,700, therefore, remained for use by the State highway department on the trunk highways.

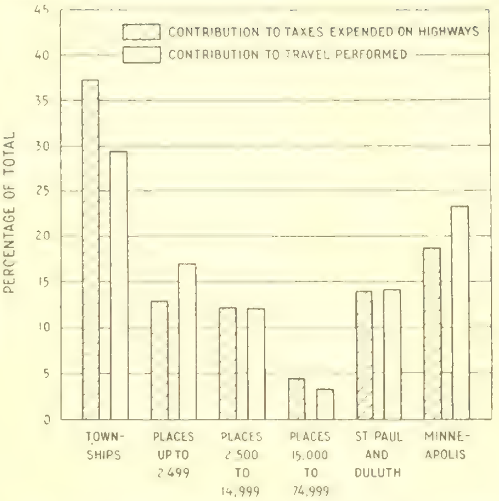
The motor-vehicle license fee data were obtained from records in the State offices. A representative sample of registrations was listed and analyzed, and questionnaires were sent to motor-vehicle owners to



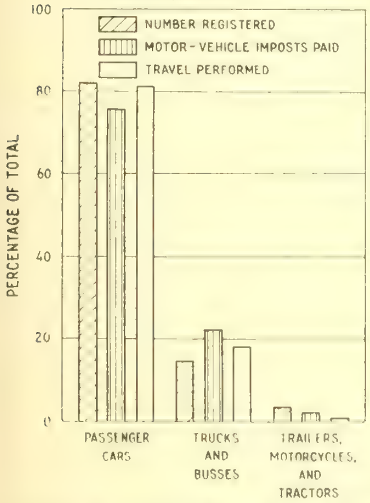
TOTAL MILEAGE OF RURAL HIGHWAY SYSTEMS AND SURFACED MILEAGE BY TYPES (TABLE 16)



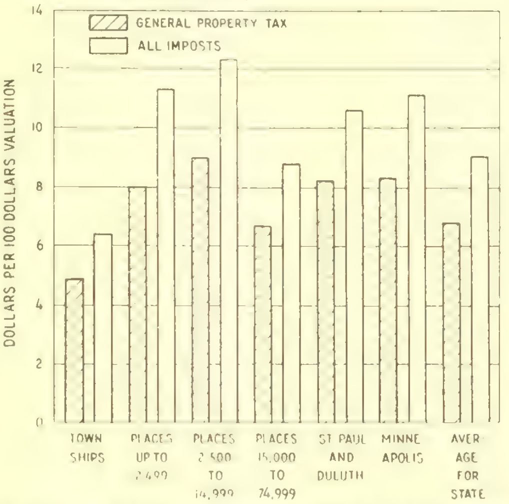
AVERAGE ANNUAL TRAVEL PER VEHICLE OF PASSENGER CARS, AND TRUCKS AND BUSSES ON THE VARIOUS CLASSES OF HIGHWAYS (TABLE 26)



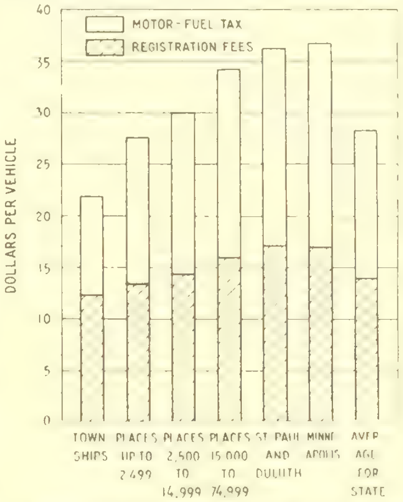
RELATIONS BETWEEN INCIDENCE OF TAXES EXPENDED ON HIGHWAYS AND TRAVEL PERFORMED BY THE RESIDENTS OF THE SEVERAL CLASSES OF LOCAL UNITS (TABLES 18 AND 21)



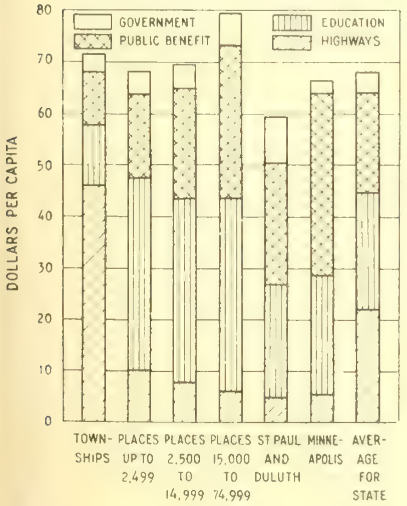
PERCENTAGE DISTRIBUTION OF ALL VEHICLES BY NUMBER REGISTERED, MOTOR-VEHICLE IMPOSTS PAID, AND TRAVEL PERFORMED (TABLE 18)



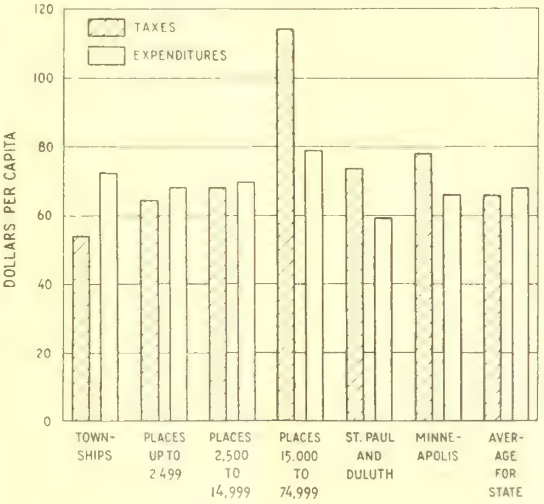
AVERAGE TAX RATES ON GENERAL PROPERTY IN THE SEVERAL CLASSES OF LOCAL UNITS AND IN THE STATE AS A WHOLE, AND RATES REQUIRED IF ALL TAXES WERE LEVIED ON GENERAL PROPERTY (TABLE 5)



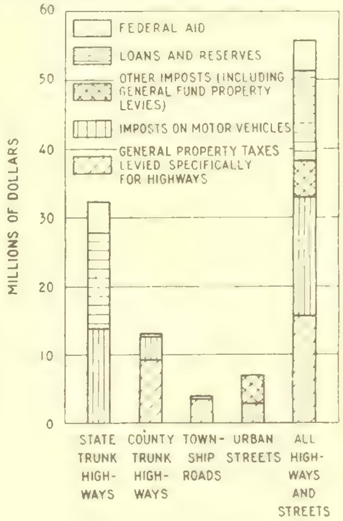
AVERAGE REGISTRATION FEES & MOTOR-FUEL TAXES PAID BY MOTOR-VEHICLE OWNERS RESIDENT IN THE SEVERAL CLASSES OF LOCAL UNITS AND IN THE STATE AS A WHOLE (TABLE 18)



PER CAPITA EXPENDITURES BY PURPOSE IN THE SEVERAL CLASSES OF LOCAL UNITS AND IN THE STATE AS A WHOLE (TABLE 9)



PER CAPITA TAXES AND EXPENDITURES IN THE SEVERAL CLASSES OF LOCAL UNITS AND IN THE STATE AS A WHOLE (TABLE 10)



TOTAL EXPENDITURES ON HIGHWAY SYSTEMS AND STREETS SHOWING SOURCES OF FUNDS (TABLE 21)

Graphical Summary of Essential Facts Disclosed by Survey of Minnesota Finances in 1932.

Table 18.—*Comparison of the several classes of local governmental units as to motor-vehicle imposts paid, population, number of vehicles registered, and contribution to total travel*

Place of ownership	Population		Motor vehicles registered [1]		Persons per vehicle	Total registration fees [2]		Registration fee per vehicle	Total motor-fuel taxes		Motor-fuel tax per vehicle	Total motor-vehicle imposts [3]	Contribution to total travel
	Number	Percentage of total	Number	Percentage of total		Amount	Percentage of total		Amount	Percentage of total			
Townships:													*Vehicle-miles*
Passenger cars			226,947	39.1	4.3	$2,842,300	35.9	$12.52	$2,078,600	27.6	$9.16	$2,920,900	1,221,700,000
Trucks and busses			41,329	40.8	23.4	509,700	25.5	12.33	675,400	27.3	16.34	1,185,100	288,400,000
Other vehicles			12,326	53.5	78.4	31,500	42.7	2.56				170,000	
Total	966,819	37.7	280,602	39.8	3.4	3,383,500	33.9	12.06	2,754,000	27.5	9.81	6,276,000	1,510,100,000
Places to 2,499:													
Passenger cars			94,516	16.3	3.6	1,246,700	15.8	13.19	1,222,300	16.3	12.93	2,469,000	716,600,000
Trucks and busses			14,572	14.4	23.3	280,000	14.1	19.21	342,800	13.8	23.52	622,800	161,000,000
Other vehicles			4,498	19.6	75.5	15,900	21.6	3.53				71,900	
Total	339,518	13.2	113,586	16.1	3.0	1,542,600	15.4	13.58	1,565,100	15.7	13.78	3,163,700	877,600,000
Places 2,500 to 14,999:													
Passenger cars			69,264	11.9	4.9	931,600	11.8	13.45	956,100	12.7	13.80	1,887,700	507,500,000
Trucks and busses			11,520	11.4	29.7	269,900	13.5	23.43	320,200	12.9	27.80	590,100	119,700,000
Other vehicles			2,281	9.9	150.0	10,000	13.6	4.38				51,000	
Total	342,054	13.3	83,065	11.8	4.1	1,211,500	12.1	14.58	1,276,300	12.8	15.37	2,528,800	627,200,000
Places 15,000 to 74,999:													
Passenger cars			15,038	2.6	5.2	216,700	2.7	14.41	251,200	3.3	16.70	467,900	133,400,000
Trucks and busses			3,984	3.9	19.6	92,400	4.6	23.19	107,900	4.4	27.08	200,300	42,800,000
Other vehicles			460	2.0	169.9	1,300	1.8	2.83				10,900	
Total	78,137	3.1	19,482	2.8	4.0	310,400	3.1	15.93	359,100	3.6	18.43	679,100	176,200,000
St. Paul and Duluth:													
Passenger cars			70,109	12.1	5.3	1,064,300	13.4	15.18	1,132,100	15.1	16.15	2,196,400	577,900,000
Trucks and busses			14,487	14.3	25.8	392,400	19.6	27.09	491,300	19.8	33.91	883,700	159,600,000
Other vehicles			998	4.3	373.8	5,000	6.8	5.01				47,300	
Total	373,069	14.6	85,594	12.1	4.4	1,461,700	14.6	17.08	1,623,400	16.2	18.97	3,127,400	737,500,000
Minneapolis:													
Passenger cars			104,675	18.0	4.4	1,612,700	20.4	15.41	1,883,800	25.0	18.00	3,496,500	1,023,200,000
Trucks and busses			15,426	15.2	30.1	454,500	22.7	29.46	538,900	21.8	34.93	993,400	179,900,000
Other vehicles			2,466	10.7	188.3	10,000	13.6	4.06				70,500	
Total	461,356	18.1	122,567	17.4	3.8	2,077,200	20.8	16.95	2,422,700	24.2	19.77	4,560,400	1,203,100,000
State total:													
Passenger cars			580,549	100.0	4.4	7,914,300	100.0	13.63	7,524,100	100.0	12.96	15,438,400	4,180,300,000
Trucks and busses			101,318	100.0	25.3	1,998,900	100.0	19.73	2,476,500	100.0	24.44	4,475,400	951,400,000
Other vehicles			23,029	100.0	111.3	73,700	100.0	3.20				421,600	
Total	2,563,953	100.0	704,896	100.0	3.6	9,986,900	100.0	14.17	10,000,600	100.0	14.19	20,335,400	5,131,700,000

[1] Registered by Minnesota residents.

[2] Paid by Minnesota residents only.

[3] Includes $347,900 of miscellaneous motor-vehicle revenues.

determine the exact allocation of motor vehicles in the rural areas and several classes of urban places. The questionnaires covered the situs of ownership in the year 1934 but the results were applied to 1932 registration figures. On the basis of the records and the replies to the questionnaires, the distribution shown in table 18 was made.

There were 706,186 motor vehicles registered in Minnesota in 1932, of which 704,896 were registered by Minnesota residents and 1,290 by nonresidents. Of the resident vehicles, 82.4 percent or 580,549 were passenger cars, 14.4 percent or 101,318 were trucks and busses, and 3.2 percent or 23,029 were other vehicles such as trailers, motorcycles, and tractors.

Approximately 40 percent of the motor vehicles were registered in the rural areas and paid 33.9 percent of the registration fees. This amounted to $12.06 per vehicle. The registration fees in the urban areas amounted to $6,603,400 or $15.56 per vehicle licensed. As the size of place increased the average license fee paid increased. The average fee per motor vehicle in Duluth, St. Paul, and Minneapolis was $17. The difference in fees is attributed to the fact that the less valuable cars tend to be registered in the rural areas. The trend is even more pronounced when the data for passenger cars and trucks and busses are analyzed separately. It is also interesting to note that the spread between the average fee paid for passenger cars and that paid for trucks and busses tended to increase as the size of the place increased.

Motor-fuel tax.—Minnesota collects a fuel tax of 3 cents per gallon on gasoline consumed by vehicles operating on the highways. Refunds are allowed for nonhighway use. The figures shown in table 18 are the net amounts collected. Collections are made by oil inspectors of the State department of agriculture, dairy, and food. Two-thirds of the net amount collected is given to the State highway department for use on the trunk highway system and one-third is given to the counties for use on the county-aid roads.

Of the State road and bridge funds that are apportioned to the counties, not less than 20 percent must be used for maintenance. While the apportionments under the State-aid act may vary from 1 percent to 3 percent of the total funds available, the statutes do not specify the determining factors as to the amount that may be made available. There is also an indefinite provision relating to the apportionment of the gasoline tax funds. While no less than 0.75 percent, and no more than 3 percent, may be apportioned to any one county, the method of apportionment is simply that "* * * in the making of such apportionment regard shall be had to the mileage of county and town roads and the traffic needs and conditions of the respective counties."

The State-aid funds paid out of the State property tax are utilized for certain county roads known as State-aid roads. The allotment of gasoline tax money to the counties is used in connection with funds raised by the towns on roads primarily having the characteristics of local rural highways, although they are designated as county-aid roads and are generally treated in the same classification as other county roads.

The cost of collecting the motor-fuel taxes was only $14,100, or 0.14 percent of the gross receipts. The cost amounted to 2 cents per vehicle.

After deducting the amount paid to the State road and bridge fund for apportionment to the counties, there remained $6,651,000 for use on State trunk routes.

To determine the incidence of the motor-fuel tax, questionnaires were sent to 22,000 motor-vehicle owners selected at random. The questionnaire requested the owner to give information regarding the average annual travel performed, the amount of gasoline consumed, and the average number of miles obtained per gallon.

The replies were analyzed and from them a distribution of motor-fuel taxes was made. Table 18 contains a tabulation of the results.

The rural areas paid 33.9 percent of the motor-vehicle registration fees and 27.5 percent of the gasoline taxes. The gasoline taxes amounted to $9.81 per vehicle. As was the case with motor-vehicle registration fees, the gasoline tax per vehicle increases as the size of place increases. Minneapolis motor-vehicle owners paid $19.77 per vehicle in gasoline taxes, and St. Paul and Duluth vehicle owners paid $18.97. This trend is explained as follows: Because of traffic conditions, the automobiles in urban areas get less mileage per gallon; the heavier vehicles are concentrated in the cities; and the average number of miles traveled annually is greater for vehicles owned in the cities.

Other motor-vehicle imposts.—Miscellaneous motor-vehicle imposts total $347,900. These imposts include minor charges against motor-vehicle owners such as chauffeurs' licenses, duplicate plates, property tax on motor vehicles in the hands of dealers, and similar charges.

Table 18 presents interesting data regarding motor-vehicle fees, and for purposes of comparison shows in addition population, registration, and travel data for the various places.

FIFTY-EIGHT PERCENT OF ALL HIGHWAY EXPENDITURES MADE ON STATE TRUNK SYSTEM

The contributions in 1932 by residents of the rural and urban areas to the costs of the highway program are shown in table 19. The table shows the total amounts that residents in each class of place contributed, both in State and local revenues. The proportion each impost bears to the total taxes levied can also be seen from this table.

Tables 20 and 21 show the sources of revenue for road and street purposes classified by type of revenue and by contributing agency. The highway systems upon which the revenues were used are also shown. These tables summarize all information on the sources of highway imposts and the highway systems upon which they were expended.

EIGHTY PERCENT OF ALL ROAD AND STREET EXPENDITURES MADE ON RURAL ROADS

Sufficient data have been obtained so that the figures on road costs for the State, county, and townships are reasonably accurate. The total expenditures for city streets were also obtained, but very little information was found concerning the respective amounts spent for construction and maintenance. For this reason it has been deemed inadvisable to estimate the proportionate amounts spent for these purposes.

Table 22 shows that of the total of $55,732,600 spent for highways in 1932, $32,149,900 or 57.7 percent was expended by the State;[2] $12,720,700 or 22.8 percent was expended by the counties; and the remainder, $10,862,000 or 19.5 percent, was expended by the local communities for rural roads and urban streets.

The amount spent on the State trunk highways includes expenditures on the urban as well as the rural portions of the trunk routes. About 11.5 percent or $3,712,100 was spent on the State trunk routes in corporate limits. Of the total of $32,149,900 spent on trunk routes, $26,299,500 or 81.8 percent was spent for construction, $3,818,400 or 11.9 percent for maintenance, and $2,032,000 or 6.3 percent for overhead.

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[2] Differences will be found between some of the figures contained in this report and figures previously released by the Bureau. The same basic figures were used in preparing the Bureau's previous reports, reports made by the Minnesota State Highway Department, and this financial survey, but there are differences in their interpretation.

This report reflects the actual net costs during the year. In the official accounts there are often credits and charges for previous years carried over into the accounts of the current year and reflected in the annual financial statements of the highway department. Such transactions have been eliminated in this survey.

TABLE 19.—*Incidence of taxation for street and highway purposes*

Paid by taxpayers in—	Type of impost										Total	
	Motor-fuel tax		Registration fees		Other motor-vehicle imposts		Special assessments		Property tax			
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Townships	$2,754,000	27.5	$3,396,600	33.9	$138,500	39.8			$10,590,900	65.1	$16,880,000	42.5
Places to 2,499	1,565,100	15.7	1,547,800	15.5	56,000	16.1	$221,400	7.3	1,563,600	9.6	[illegible]	12.5
Places 2,500 to 14,999	1,276,300	12.8	1,215,300	12.1	41,000	11.8	464,200	15.2	1,341,800	8.3	4,338,600	10.9
Places 15,000 to 74,999	359,100	3.6	311,300	3.1	9,600	2.8	101,600	3.3	729,900	4.5	1,511,500	3.8
St. Paul and Duluth	1,623,400	16.2	1,465,700	14.6	42,300	12.1	815,300	26.7	[illegible]	5.5	4,837,200	12.2
Minneapolis	2,422,700	24.2	2,082,900	20.8	60,500	17.4	1,450,400	47.5	1,144,400	7.0	7,160,900	18.1
Total	10,000,600	100.0	10,019,600	100.0	347,900	100.0	3,052,900	100.0	16,261,100	100.0	39,682,100	100.0
Percentage of total		25.2		25.2		.9		7.7		41.0		100.0

[1] Includes $32,700 of nonresident fees.

Snow Removal Is an Item of Highway Maintenance Expenditure.

Table 20.—*Funds expended on the several highway systems and the city streets in 1932, and the approximate amounts and percentages of these funds provided by imposts made by the various governmental units and by loan and reserve funds*

Highway system and form of revenue	Governmental agency providing funds					Percentage of total current tax funds	Percentage of total funds
	Federal Government	State	Counties	Local governments	Total		
State trunk system:							
Loans and reserves		$13,861,000			$13,861,000		
Current taxes	$4,457,200	13,831,700			18,288,900	43.8	
Total	4,457,200	27,692,700			32,149,900		57.7
Percentage of total	13.9	86.1			100.0		
County highways:							
Loans and reserves			$94,600		94,600		
Current taxes		5,219,700	7,406,400		12,626,100	30.3	
Total		5,219,700	7,501,000		12,720,700		22.8
Percentage of total		41.0	59.0		100.0		
Local township roads:							
Loans and reserves				$43,500	43,500		
Current taxes				3,850,800	3,850,800	9.2	
Total				3,894,300	3,894,300		7.0
Percentage of total				100.0	100.0		
City streets:							
Loans and reserves							
Current taxes				6,967,700	6,967,700	16.7	
Total				6,967,700	6,967,700		12.5
Percentage of total				100.0	100.0		
All roads and streets:							
Loans and reserves		13,861,000	94,600	43,500	13,999,100		
Current taxes	4,457,200	19,051,400	7,406,400	10,818,500	41,733,500	100.0	
Total	4,457,200	32,912,400	7,501,000	10,862,000	55,732,600		100.0
Percentage of total	8.0	59.0	13.5	19.5	100.0		

Table 21.—*Approximate amounts of the 1932 taxes and imposts expended on the current highway and street program listed according to highway system, type of tax, and class of local unit in which the tax is paid*

IMPOSTS ON GENERAL PROPERTY LEVIED SPECIFICALLY FOR HIGHWAYS

Paid by taxpayers in—	Highway system										
	State trunk		County trunk		Township		Urban streets		All highways and streets		
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Percentage of total
Townships			$4,830,000	55.6	$3,850,800	44.4			$8,680,800	100.0	54.8
Places to 2,499			1,295,700	70.1			$551,600	29.9	1,847,300	100.0	11.6
Places 2,500 to 14,999			1,125,400	64.1			631,000	35.9	1,756,400	100.0	11.1
Places 15,000 to 74,999			664,600	65.8			345,300	34.2	1,009,900	100.0	6.4
St. Paul and Duluth			865,500	59.8			581,600	40.2	1,447,100	100.0	9.1
Minneapolis			509,400	45.9			600,600	54.1	1,110,000	100.0	7.0
Total			9,290,600	58.6	3,850,800	24.3	2,710,100	17.1	15,851,500	100.0	100.0

IMPOSTS ON MOTOR VEHICLES

Paid by taxpayers in—	State trunk Amount	State trunk Percent	County trunk Amount	County trunk Percent	Township Amount	Township Percent	Urban streets Amount	Urban streets Percent	All highways and streets Amount	All highways and streets Percent	Percentage of total
Townships	$4,263,300	82.3	$917,300	17.7					$5,180,600	100.0	30.2
Places to 2,499	2,157,200	80.5	523,700	19.5					2,680,900	100.0	15.6
Places 2,500 to 14,999	1,720,200	80.1	426,900	19.9					2,147,100	100.0	12.5
Places 15,000 to 74,999	462,000	79.4	120,100	20.6					582,100	100.0	3.4
St. Paul and Duluth	2,125,900	79.7	540,300	20.3					2,666,200	100.0	15.5
Minneapolis	3,103,100	79.4	807,200	20.6					3,910,300	100.0	22.8
Total	13,831,700	80.6	3,335,500	19.4					17,167,200	100.0	100.0

OTHER IMPOSTS (INCLUDING GENERAL FUND PROPERTY LEVIES)

Paid by taxpayers in—	State trunk Amount	State trunk Percent	County trunk Amount	County trunk Percent	Township Amount	Township Percent	Urban streets Amount	Urban streets Percent	All highways and streets Amount	All highways and streets Percent	Percentage of total
Townships											
Places to 2,499							$310,800	100.0	$310,800	100.0	7.3
Places 2,500 to 14,999							647,200	100.0	647,200	100.0	15.2
Places 15,000 to 74,999							140,500	100.0	140,500	100.0	3.3
St. Paul and Duluth							1,136,700	100.0	1,136,700	100.0	26.7
Minneapolis							2,022,400	100.0	2,022,400	100.0	47.5
Total							4,257,600	100.0	4,257,600	100.0	100.0

ALL TAXES AND IMPOSTS

Paid by taxpayers in—	State trunk Amount	State trunk Percent	County trunk Amount	County trunk Percent	Township Amount	Township Percent	Urban streets Amount	Urban streets Percent	All highways and streets Amount	All highways and streets Percent	Percentage of total
Townships	$4,263,300	30.7	$5,747,300	41.5	$3,850,800	27.8			$13,861,400	100.0	37.2
Places to 2,499	2,157,200	44.6	1,819,400	37.6			$862,400	17.8	4,839,000	100.0	13.0
Places 2,500 to 14,999	1,720,200	37.8	1,552,300	34.1			1,278,200	28.1	4,550,700	100.0	12.2
Places 15,000 to 74,999	462,000	26.7	784,700	45.3			485,800	28.0	1,732,500	100.0	4.6
St. Paul and Duluth	2,125,900	40.5	1,405,800	26.8			1,718,300	32.7	5,250,000	100.0	14.1
Minneapolis	3,103,100	44.1	1,316,600	18.7			2,623,000	37.2	7,042,700	100.0	18.9
Total	13,831,700	37.1	12,626,100	33.9	3,850,800	10.3	6,967,700	18.7	37,276,300	100.0	100.0
Federal aid	4,457,200	100.0							4,457,200	100.0	
Loans and reserves	13,861,000	99.0	94,600	0.7	43,500	0.3			13,999,100	100.0	
Grand total	32,149,900	57.7	12,720,700	22.8	3,894,300	7.0	6,967,700	12.5	55,732,600	100.0	

Table 22.—*Highway and street expenditures in 1932, including prorated overhead costs*

Expended by—	Amount	Percent	Expended on	
			Rural roads	Urban streets
State (State system)	$32,149,900	57.7	$28,437,800	$3,712,100
Counties (county system)	12,720,700	22.8	12,191,000	529,700
Townships	3,894,300	7.0	3,894,300	
Places to 2,499	862,400	1.5		862,400
Places 2,500 to 14,999	1,278,200	2.3		1,278,200
Places 15,000 to 74,999	485,800	.9		485,800
St. Paul and Duluth	1,718,300	3.1		1,718,300
Minneapolis	2,623,000	4.7		2,623,000
Total	55,732,600	100.0	44,523,100	11,209,500

Table 23.—*Construction and maintenance expenditures in 1932 on the State trunk system, in both rural and urban areas* [1]

Section of State trunk system	Construction		Maintenance		Construction and maintenance	
	Amount	Percent	Amount	Percent	Amount	Percent
Rural	$23,204,200	88.2	$3,413,600	89.4	$26,617,800	88.4
Urban	3,095,300	11.8	404,800	10.6	3,500,100	11.6
Total	26,299,500	100.0	3,818,400	100.0	30,117,900	100.0

[1] Interest, engineering, supervision, and other undistributed overhead costs are not included.

Table 23 shows the expenditures on the rural and urban portions of the State trunk system divided between construction and maintenance. The expenditures for general administration and other overhead are not included.

Expenditures for construction include costs of planning and engineering, grading, draining, surfacing, and the machinery used in connection with construction work. Expenditures for the construction of bridges and grade separations and reconstruction are also included. The costs of engineering, patching, patroling, machinery, marking, and temporary improvements such as light oiling and regraveling comprise the maintenance expenditures.

All engineering costs and highway department salaries that cannot be definitely allocated to construction or maintenance are included in overhead expenditures. The cost of administering the motor-fuel taxes, interest payments on bonds (but not principal payments), and damages and claims are also overhead expenditures.

Of the $12,720,700 spent by county governments for highways in both urban and rural areas, $5,181,000, or 40.7 percent, was for construction; $5,700,500, or 44.8 percent, was for maintenance, and $1,839,200, or 14.5 percent, was for overhead.

The counties spent $529,700, or 4.2 percent, of the total spent on the urban portions of the county roads (table 22).

Township expenditures for local rural roads were $3,894,300. The construction costs were $2,697,300, or 69.3 percent; the maintenance costs were $1,097,400, or 28.2 percent; and the overhead costs were $99,600, or 2.5 percent. The expenditures by urban places on streets were $6,967,700 (table 22).

The annual travel on the various highway systems was determined by the road-use survey. The total expenditures on the several highway systems reduced to cost per vehicle-mile are shown in table 24.

Table 24.—*Highway expenditures per vehicle-mile of travel in 1932 on the several systems of roads as determined by the Minnesota road-use survey*

Highway system	Highway expenditures per vehicle-mile	Annual travel
	Cents	*Vehicle-miles*
State system	1.4	2,276,400,000
County road	1.3	1,016,500,000
Township road	1.3	311,200,000
City streets	.5	1,527,600,000
All highways	1.1	5,131,700,000

HIGHWAY TAXES AND EXPENDITURES COMPARED

Expenditures by the State and counties are made for the benefit of residents in both the rural and urban areas. The total highway expenditure in these areas, therefore, is the sum of the State and county highway expenditures plus the amount spent by the locality itself.

The total amount spent for highways in the rural areas of the State was $44,523,100, or 79.9 percent, of the total. The balance, $11,209,500, was spent in the urban places. Table 25 shows the allocation of highway expenditures and highway taxes by the several local units of government. In the entire State the highway expenditures were 40 percent more than the taxes collected for them.

The outstanding highway debt of all governmental units in Minnesota in 1932 was $95,051,900. The State accounted for $42,759,200 or 45 percent of the total; the counties accounted for $16,430,100 or 17.3 percent; the cities of Minneapolis, St. Paul, and Duluth accounted for $30,041,300 or 31.6 percent;

Table 25.—*Comparison of street and highway taxes and expenditures in 1932 by places*

Type of place	Street and highway taxes paid		Street and highway expenditures		Ratio of expenditures to taxes
	Amount	Percent	Amount	Percent	
Townships	$16,880,000	42.5	$44,523,100	79.9	2.64
Places to 2,499	4,953,900	12.5	3,417,600	6.1	.69
Places 2,500 to 14,999	4,338,600	10.9	2,808,800	5.0	.65
Places 15,000 to 74,999	1,511,500	3.8	537,400	1.0	.36
St. Paul and Duluth	4,837,200	12.2	1,822,700	3.3	.38
Minneapolis	7,160,900	18.1	2,623,000	4.7	.37
Total	39,682,100	100.0	55,732,600	100.0	1.40

Table 26.—*Average number of miles traveled per vehicle on the highway systems and local streets of Minnesota by Minnesota motor vehicles in 1932*

Place of ownership and type of vehicle	State trunk highways	County trunk highways	Local roads and streets	Total
	Miles per vehicle	*Miles per vehicle*	*Miles per vehicle*	*Miles per vehicle*
Townships:				
Passenger cars	2,202	2,315	866	5,383
Trucks and busses	3,329	2,491	1,158	6,978
All vehicles	2,375	2,342	912	5,629
Percentage of total	42.2	41.6	16.2	100.0
Places to 2,499:				
Passenger cars	4,602	1,858	1,122	7,582
Trucks and busses	5,735	2,762	2,552	11,049
All vehicles	4,755	1,979	1,311	8,045
Percentage of total	59.1	24.6	16.3	100.0
Places 2,500 to 14,999:				
Passenger cars	4,404	1,077	1,846	7,327
Trucks and busses	4,686	1,611	4,094	10,391
All vehicles	4,441	1,157	2,166	7,764
Percentage of total	57.2	14.9	27.9	100.0
Places 15,000 to 74,999:				
Passenger cars	4,799	825	3,247	8,871
Trucks and busses	2,815	1,504	6,424	10,743
All vehicles	4,381	973	3,909	9,263
Percentage of total	47.3	10.5	42.2	100.0
St. Paul and Duluth:				
Passenger cars	2,720	264	5,259	8,243
Trucks and busses	3,349	231	7,437	11,017
All vehicles	2,824	262	5,632	8,718
Percentage of total	32.4	3.0	64.6	100.0
Minneapolis:				
Passenger cars	3,626	362	5,787	9,775
Trucks and busses	3,860	35	7,767	11,662
All vehicles	3,656	321	6,040	10,017
Percentage of total	36.5	3.2	60.3	100.0
State total				
Passenger cars	3,240	1,455	2,506	7,201
Trucks and busses	3,897	1,690	3,803	9,390
All vehicles	3,342	1,490	2,694	7,526
Percentage of total	44.4	19.8	35.8	100.0

Table 27.—*Percentage distribution of travel on the various highway systems in Minnesota in 1932 provided by vehicles in the various classes of places*

DISTRIBUTION BY PLACE OF ORIGIN OF TRAFFIC

Unit of government where traffic originated	Highway system on which travel was performed			
	State system	County roads	Local roads and streets	All highways
	Percent	*Percent*	*Percent*	*Percent*
Townships	28.0	61.8	13.3	29.4
Places to 2,499	22.8	21.2	7.8	17.1
Places to 2,500 to 14,999	15.8	9.2	9.5	12.2
Places 15,000 to 74,999	3.6	1.8	4.0	3.4
St. Paul and Duluth	10.5	2.2	25.9	14.4
Minneapolis	19.3	3.8	39.5	23.5
Total	100.0	100.0	100.0	100.0

DISTRIBUTION BY HIGHWAY SYSTEM ON WHICH TRAVEL WAS PERFORMED

Townships	42.2	41.6	16.2	100
Places to 2,499	59.1	24.6	16.3	100
Places 2,500 to 14,999	57.2	14.9	27.9	100
Places 15,000 to 74,999	47.3	10.5	42.2	100
St. Paul and Duluth	32.4	3.0	64.6	100
Minneapolis	36.5	3.2	60.3	100
Total	44.4	19.8	35.8	100

and the townships and smaller municipalities accounted for $5,821,300 or 6.1 percent. Twenty-nine million dollars of trunk highway bonds and $13,759,200 of county highway reimbursement bonds assumed by the State comprise the State highway debt. The county highway debt was contracted to provide through traffic facilities to supplement the State trunk system. Hennepin and Ramsey counties alone incurred $10,922,200 or 66.4 percent of the total county highway indebtedness.

The townships bonded themselves to the extent of $1,233,300 or 3.4 percent of the local debt for highways. Minneapolis, St. Paul, and Duluth incurred 83.8 percent of the total local rural and urban highway debt. As the size of place increases the demand for transportation facilities increases. This fact is reflected in per-capita debts for highway purposes which range from $1.28 in the townships to $40.28 in Minneapolis.

Highway debt service in 1932 was $8,487,200, of which $4,085,000 was for interest and $4,402,200 for principal payments. The State paid $4,150,800, of which $1,713,900 was for interest and $2,418,900 for principal. The counties spent $1,284,400, of which $739,300 was for interest and $545,100 for principal. The various other units spent $3,052,000, of which $1,613,800 was for interest and $1,438,200 for debt retirement.

Part of the motor-vehicle registration fees are impounded for the payment of interest and principal on the State highway debt. The debt service of other units of government is paid from property tax receipts.

RELATIONS BETWEEN HIGHWAY TAXES PAID, HIGHWAY EXPENDITURES, AND TRAVEL

The total mileage of rural highways in Minnesota in 1932 was 111,475. The State highway system consisted of 6,772 miles; the county highway system contained 32,126 miles; and the local township roads consisted of 72,577 miles. No data are available on mileage of village and city streets.

The total travel (exclusive of travel by out-of-State vehicles) on all roads and streets in Minnesota during the year 1932 was over 5 billion vehicle-miles, of which 29.4 percent was performed by vehicles of rural ownership; 17.1 percent by vehicles owned in incorporated places having a population to 2,499; 12.2 percent by vehicles owned in places 2,500 to 14,999 population; 3.4 percent by vehicles owned in places 15,000 to 74,999; 14.4 percent by vehicles owned in St. Paul and Duluth; and 23.5 percent by vehicles owned in Minneapolis.

Expenditures on the State highway system in 1932 were $32,149,900; on the county system, $12,720,700; on local township roads, $3,894,300; and on city streets, $6,967,700.

Of the total property taxes expended on all roads and streets, 58.6 percent was expended on county highways, 24.3 percent on the local township roads, and 17.1 percent on urban streets.

Of the total motor-vehicle taxes expended on all roads and streets, 80.6 percent was expended on State trunk highways, 19.4 percent on county trunk highways, and none on urban streets.

Of all taxes and imposts expended on all roads and streets, rural property and motor-vehicle owners paid 36.8 percent, and travel by rural-owned vehicles made up 29.4 percent of the total travel on all roads and streets; city and village property and motor-vehicle owners paid 63.2 percent, and travel by city- and village-owned vehicles made up 70.6 percent of the total travel.

NEARLY TWO-THIRDS OF ALL MOTOR-VEHICLE TRAVEL PERFORMED ON STATE AND COUNTY TRUNK HIGHWAYS

Data regarding the average annual travel of motor vehicles have been developed from the gasoline tax questionnaires and the road-use survey. The road-use survey discloses further the approximate amount of travel upon the different highway systems in the several classes of localities and the origin of that travel.

The road-use survey is not a traffic count. For the information necessary to make the study, 7,500 personal interviews were made. Motor-vehicle, population, and occupation data were used as bases for the selection of a sample. The obtaining of an accurate cross-section was thus insured. During the work statistical checks were constantly made. The results obtained in one section were compared with those obtained in other sections and with the total; and the average mileages and gasoline consumption for specific localities obtained from the questionnaires used to allocate the gasoline taxes were compared with similar figures obtained from the interviews.

The extent of tourist and other travel by out-of-State vehicles was not disclosed by the road-use survey. It is estimated, however, that this constitutes but a small fraction of the total traffic and is almost entirely on the State system.

Minnesota motor vehicles in 1932 traveled approximately 5,131,700,000 vehicle miles upon all highways in the State. Of this mileage traveled, 2,276,400,000 miles or 44.4 percent was upon the State trunk routes, 1,016,500,000 or 19.8 percent upon county roads, 311,200,000 or 6.1 percent upon local town roads, and 1,527,600,000 or 29.7 percent was upon urban streets.

Of the total travel, 4,180,300,000 vehicle-miles was the travel by passenger cars and 951,400,000 vehicle-miles the travel by trucks and busses.

In table 26 the figures for the travel performed by passenger cars and by trucks and busses owned in the several classes of places upon the State, county, and local roads are shown as the average annual miles per vehicle. It is evident that: (1) Trucks and busses travel more than do passenger cars; (2) urban-owned vehicles travel more than do rural-owned vehicles; (3) the amount of travel tends to increase as the size of place increases; and (4) almost half of the total travel was upon State trunk highways.

Table 27 expresses in percentages the origin of travel on the various highway systems. From this table it is seen that the primary use of the county roads is by rural residents. The extensive use of the State system by the vehicles of all communities is again emphasized. Table 27 also gives the percentage of travel divided among the highway systems upon which it was performed.

Common-carrier vehicles do not contribute heavily to the total travel on Minnesota highways. Data concerning the travel of all motor vehicles under the jurisdiction of the Minnesota Railroad and Warehouse Commission were analyzed and tabulated. This travel accounts for only about 18,800,000 vehicle-miles, or 0.4 percent of a total of over 5,000,000,000 vehicle-miles.

TRAVEL PER VEHICLE GREATEST FOR VEHICLES OWNED IN LARGE CITIES

From the gasoline tax questionnaires and the road-use interviews the average gallons of gasoline purchased annually in the State by Minnesota motor-vehicle owners were computed. Table 28 shows this tabulation in detail. The gasoline consumption per vehicle increases as the size of place increases and the average for trucks and busses is higher than for passenger cars.

TABLE 28.—*Average annual travel and gasoline consumption per vehicle in 1932 by place of ownership*

Place of ownership	Average annual gasoline consumption by—			Average annual travel by—		
	Passenger cars	Trucks and busses	All vehicles	Passenger cars	Trucks and busses	All vehicles
	Gallons per vehicle	*Gallons per vehicle*	*Gallons per vehicle*	*Miles per vehicle*	*Miles per vehicle*	*Miles per vehicle*
Townships	345	616	370	5,383	6,978	5,629
Places to 2,499	487	886	519	7,582	11,049	8,045
Places 2,500 to 14,999	520	1,048	579	7,327	10,391	7,764
Places 15,000 to 74,999	629	1,020	694	8,871	10,743	9,263
St. Paul and Duluth	608	1,277	714	8,243	11,017	8,718
Minneapolis	678	1,346	745	9,775	11,662	10,017
Entire State	488	921	534	7,201	9,390	7,526

Table 29 presents in concise form the relations existing between the various classes of places with respect to five of the major sets of facts determined by this survey.

Table 30 presents more clearly the relation between the taxes received and expenditures as finally made. The figures are based on results found in previous sections of the report. This table shows the source of each $1,000 in taxes by type of impost and by class of place responsible for its payment. Highway expenditures are further shown by highway system and source of revenue. It should not be inferred from this table that taxes equal expenditures or that the $1,000 unit is identical; the figures have been assembled on this basis only to facilitate comparisons between taxes and expenditures.

TABLE 29.—*Percentage distribution of population, motor-vehicle ownership, property valuation, taxes paid, and expenditures made in the several classes of places in 1932*

Class of place	Population	Motor-vehicle ownership	Taxable valuation	Total taxes paid	Total expenditures as made
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Townships	37.7	39.8	42.9	30.3	39.4
Places to 2,499	13.2	16.1	10.2	12.8	13.3
Places 2,500 to 14,999	13.3	11.8	10.2	13.8	13.6
Places 15,000 to 74,999	3.1	2.8	5.4	5.3	3.5
St. Paul and Duluth	14.6	12.1	13.7	16.2	12.7
Minneapolis	18.1	17.4	17.6	21.6	17.5
Total	100.0	100.0	100.0	100.0	100.0

SUMMARY

1. There were no expenditures of funds from general property taxes on State highways.

2. Rural property paid no tax for local urban streets and urban property paid no tax for local township roads.

3. Of the total rural property taxes expended for highway purposes—

   (*a*) 55.6 percent was expended on county trunk highways;

   (*b*) 44.4 percent was expended on local township roads.

4. Of the total property tax raised from urban communities and expended for street and highway purposes—

   (*a*) 62.2 percent was expended on county highways;

   (*b*) 37.8 percent was expended on urban streets.

5. Since, of the total assessed property valuation of $1,884,238,200, 42.9 percent or $808,798,600 was in rural areas, and 57.1 percent, or $1,075,439,600 was in the urban units—

   (*a*) Expenditures from property taxes for all highways and streets were at the following rates per $100 of assessed valuation:

   Rural—107.3 cents.
   Urban—66.7 cents.

TABLE 30.—*Comparison of taxation and expenditures in Minnesota in 1932*

$1,000 in taxes			$1,000 in expenditures				
Residents of—	Pay	In—	Division by purpose	Subdivision by highway system	Source of expenditures	Amount	Percent
Townships	$232.10	General property taxes, $751.12.	Education, $332.08.	State trunk highways, $183.25	Taxes paid in—		
Places to 2,499	90.89				Townships	$24.29	13.2
Places 2,500 to 14,999	101.40				Incorporated places	54.51	29.8
Places 15,000 to 74,999	40.56				Federal aid	25.47	13.9
St. Paul and Duluth	123.93				Loans and reserves	78.98	43.1
Minneapolis	162.24						
Townships	37.08	Motor-vehicle taxes, $119.99.	Highways, $317.59.	County trunk highways, $72.41.	Taxes paid in—		
Places to 2,499	18.72				Townships	32.73	45.2
Places 2,500 to 14,999	14.88				Incorporated places	39.17	54.1
Places 15,000 to 74,999	3.96				Loans and reserves	.51	.7
St. Paul and Duluth	18.48						
Minneapolis	26.87						
			Public benefit, $283.51.	Township roads, $22.23	Taxes paid in—		
					Townships	21.99	98.9
					Incorporated places	-----	-----
					Loans and reserves	.24	1.1
Townships	33.96	Miscellaneous taxes, $128.89.	Government, $66.82	Urban streets, $39.70.	Taxes paid in—		
Places to 2,499	18.82				Townships	-----	-----
Places 2,500 to 14,999	22.01				Incorporated places	39.70	100.0
Places 15,000 to 74,999	8.22				Loans and reserves	-----	-----
St. Paul and Duluth	19.46						
Minneapolis	26.42						

(*b*) Expenditures from property taxes for county highways were at the following rates per $100 valuation:
Rural—59.7 cents.
Urban—41.5 cents.

(*c*) Expenditures from property taxes for local township roads were at the following rates per $100 valuation:
Rural—47.6 cents.
Urban—No tax.

(*d*) Expenditures from property taxes for local urban streets were at the following rates per $100 valuation:
Rural—No tax.
Urban—25.2 cents.

6. Of the total property taxes expended on all roads—
(*a*) 58.6 percent was expended on county highways;
(*b*) 24.3 percent was expended on local township roads;
(*c*) 17.1 percent was expended on urban streets.

7. Of the total motor-vehicle imposts expended on all classes of roads and streets—
(*a*) Rural motor-vehicle owners paid 30.2 percent and contributed 29.4 percent of the total travel on all roads and streets;
(*b*) Urban motor-vehicle owners paid 69.8 percent and contributed 70.6 percent of the total travel.

8. Of the total motor-vehicle imposts expended on all classes of roads and streets—
(*a*) 80.6 percent was expended on the State trunk highways;
(*b*) 19.4 percent was expended on the county highways.

9. Of all taxes and imposts expended on all roads and streets—
(*a*) 37.1 percent was expended on State trunk highways;
(*b*) 33.9 percent was expended on county highways;
(*c*) 10.3 percent was expended on local township roads;
(*d*) 18.7 percent was expended on urban streets.

10. Of all taxes and imposts expended on all roads and streets—
(*a*) Rural property and motor-vehicle owners paid 36.8 percent and contributed 29.4 percent of the total travel on all roads and streets;
(*b*) City and village property and motor-vehicle owners paid 63.2 percent and contributed 70.6 percent of the travel.

STATUS OF FEDERAL AID HIGHWAY PROJECTS

(1936 FUNDS)

AS OF FEBRUARY 29, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 158,857	$ 105,903	3.0	$ 1,722,376	$ 1,436,391	98.1	$ 53,440	$ 26,720		212,333
Arkansas	2,142,723										2,142,723
California	4,756,959	124,803	72,230	5.2	3,168,070	1,824,144	40.7	1,659,030	942,306	40.3	1,918,279
Colorado	2,288,811	25,046	14,026	.1	1,748,648	979,242	78.9	631,068	349,278	13.2	946,265
Connecticut	791,253							212,492	95,909	3.8	695,344
Delaware	609,375							483,982	240,196	38.2	369,179
Florida	1,655,723				674,678	337,339	23.8	218,968	109,484	8.8	1,208,900
Georgia	3,168,221				944,637	466,093	64.0	1,303,626	651,813	74.5	2,050,315
Idaho	1,531,162	292,520	164,327	44.6	1,255,005	748,902	121.4	223,546	133,753	6.5	484,180
Illinois	5,160,696				3,056,403	1,525,847	60.4	3,369,466	1,684,733	52.1	1,950,116
Indiana	3,087,613	244,757	122,373	6.9	3,605,195	1,798,745	118.0	2,175,968	1,087,838	66.3	78,657
Iowa	3,231,718	224,362	105,460	57.5	4,200,560	1,978,570	190.7	1,535,867	721,175	57.8	426,513
Kansas	3,317,054	10,829	5,414	6.7	616,918	308,459	117.3	2,702,993	1,351,496	262.0	1,651,685
Kentucky	2,304,143	604,406	302,203	39.4	1,513,322	737,079	99.9	1,501,798	716,618	40.2	548,243
Louisiana	1,776,939	107,553	53,776	3.7	1,353,102	676,551	49.2	864,378	432,189	30.3	614,423
Maine	1,090,167	113,605	56,802	2.1	1,504,065	752,033	49.6	94,663	47,332	1.9	234,000
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877							396,055	198,028	3.1	1,543,849
Michigan	3,837,292	1,026,500	513,250	33.2	3,120,318	1,557,434	125.8	2,863,750	1,431,875	103.0	334,733
Minnesota	3,423,306	334,238	143,116	12.2	2,963,930	1,248,340	180.1	1,115,779	501,609	122.4	1,530,241
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,176,793	588,396	221.1	3,177,814	1,588,907	121.2	356,013	178,007	27.8	1,445,546
Montana	2,560,449	691,680	387,272	141.9	1,007,050	563,847	84.3	1,918,771	1,074,319	146.5	535,011
Nebraska	2,581,663	1,116,878	558,439	66.5	644,552	341,638	68.2	11,054	5,527	5.2	1,676,059
Nevada	1,595,501	116,744	100,180	55.4	883,442	764,796	95.8	27,646	23,932		706,593
New Hampshire	609,375				672,702	330,042	20.9	22,459	11,192	1.1	268,141
New Jersey	1,675,751				1,474,928	737,464	26.4	1,972,969	899,954	13.9	38,333
New Mexico	1,999,299	159,058	96,739	18.4	1,877,956	1,148,308	144.2	417,651	284,004	13.0	470,248
New York	6,150,106				8,247,455	4,080,100	153.9	1,607,300	789,275	22.5	1,280,731
North Carolina	2,938,657				1,141,761	570,291	189.5	166,058	83,029	24.4	2,285,337
North Dakota	1,960,162										1,960,162
Ohio	4,565,435				1,053,782	526,792	11.3	3,026,800	1,512,200	40.6	2,526,443
Oklahoma	2,947,521				1,603,159	840,205	52.3	202,131	106,220	9.7	2,001,096
Oregon	2,044,633				2,347,733	1,419,720	87.5	846,944	516,636	17.0	108,277
Pennsylvania	5,348,062	60,985	30,493	1.6	4,047,072	2,023,536	56.8	2,080,148	1,039,358	31.7	2,254,675
Rhode Island	609,375										609,375
South Carolina	1,692,896				50,787	25,393					1,667,503
South Dakota	2,036,775				516,850	283,389	35.2	296,953	162,819	49.3	1,590,567
Tennessee	2,638,159	43,106	21,553	1.8	1,222,959	611,480	56.5	149,950	74,975	2.2	1,930,151
Texas	7,777,504	397,808	198,700	25.9	6,522,622	3,253,609	362.4	1,783,205	884,981	106.7	3,440,214
Utah	1,410,752	267,727	193,299	17.0	809,658	551,632	61.6	556,533	358,082	27.5	307,739
Vermont	609,375	25,988	12,994	2.9	1,093,744	546,872	50.8	52,043	26,021	4.7	23,488
Virginia	2,278,475				373,687	186,843	10.1	1,687,245	843,623	62.4	1,248,009
Washington	1,949,957	637,523	335,800	18.8	1,756,927	924,149	51.4	461,855	242,770	13.2	447,238
West Virginia	1,356,793	87,161	43,581	3.0	490,373	245,186	29.1	371,799	185,900	12.7	882,126
Wisconsin	3,045,557	375,306	187,653	14.1	1,312,394	655,060	62.4	725,939	360,377	21.6	1,842,467
Wyoming	1,559,444	522,317	321,249	83.6	1,968,673	1,212,486	191.0	46,782	23,391		2,318
District of Columbia											
Hawaii	609,375				67,469	33,734	.5	203,132	99,148	3.0	476,493
TOTALS	121,875,000	8,946,550	4,735,228	886.6	75,812,776	39,840,648	3,441.2	40,398,249	20,508,092	1,581.1	56,791,032

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF FEBRUARY 29, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 84,629	$ 84,629	10.9	$ 2,416,263	$ 2,416,263	66.4	$ 1,092,331	$ 1,092,331	41.5	$ 642,521
Arizona	2,569,841				1,218,766	1,161,624	69.6	929,024	590,863	55.5	732,726
Arkansas	3,352,061				1,373,930	1,372,312	102.6	1,083,362	1,081,561	107.9	898,188
California	7,747,928	11,043	10,500	7.2	3,835,105	3,653,852	159.3	1,743,716	1,706,864	50.9	2,376,713
Colorado	3,395,263	38,291	38,291	1.5	1,064,534	1,064,143	71.7	641,682	641,682	12.8	1,651,147
Connecticut	1,418,709										1,418,709
Delaware	900,310				163,589	163,589	19.2	414,054	414,053	39.6	322,667
Florida	2,597,144				1,010,892	993,019	37.6	708,348	708,348	17.0	895,777
Georgia	4,988,967				400,541	400,541	25.7	133,105	133,105	9.3	4,455,322
Idaho	2,222,747				1,042,354	1,039,713	87.7	273,196	245,986	24.8	937,048
Illinois	8,694,009				2,684,557	2,684,557	115.8	3,668,848	3,668,848	274.2	2,340,604
Indiana	4,941,255				1,096,432	1,096,432	51.9	3,165,369	3,165,369	174.5	679,453
Iowa	4,991,664	15,034	14,100	6.6	757,552	723,065	60.6	1,622,893	1,543,934	217.8	2,710,565
Kansas	4,994,975	3,552	3,552	1.8	1,627,778	1,627,778	180.1	2,163,149	2,162,149	134.7	1,201,497
Kentucky	3,726,271				923,165	923,165	148.4	1,614,259	1,599,243	160.2	1,203,863
Louisiana	2,890,429							817,136	544,923	36.1	2,345,506
Maine	1,676,799				704,321	704,321	33.4	709,643	709,095	29.7	263,382
Maryland	1,750,738							338,360	304,528	12.3	1,446,210
Massachusetts	3,262,885							115,246	115,246	1.1	3,147,639
Michigan	6,301,414	449,100	449,100	25.4	4,790,471	4,730,441	219.3	850,650	850,650	35.4	271,223
Minnesota	5,277,145	55,973	55,973	37.5	1,194,268	1,112,592	79.7	2,030,748	1,740,392	539.2	2,368,189
Mississippi	3,457,552				1,519,019	1,515,926	81.2	638,746	638,746	51.1	1,302,880
Missouri	6,012,652	94,525	94,525	59.0	1,892,404	1,892,404	372.4	1,668,768	1,668,768	294.6	2,356,955
Montana	3,676,416				2,064,522	2,064,522	113.9	1,174,460	1,174,460	63.1	437,433
Nebraska	3,870,739				1,096,794	1,067,688	103.0	1,151,199	1,151,199	119.6	1,651,852
Nevada	2,243,074	13,570	13,570		1,536,578	1,497,008	59.4	108,971	108,971	5.6	623,524
New Hampshire	945,225				257,318	255,212	7.9	223,046	162,899	9.8	527,114
New Jersey	3,129,805				507,749	507,749	8.5	1,183,286	1,133,286	4.4	1,438,770
New Mexico	2,871,397				1,406,674	1,406,674	105.1	673,141	673,141	48.0	791,581
New York	11,046,377				4,132,138	4,076,148	32.8	2,653,090	2,467,179	35.9	4,503,049
North Carolina	4,720,173				1,281,584	1,281,584	112.0	1,091,466	988,263	70.8	2,450,326
North Dakota	2,867,245	140,150	140,150	20.8	319,882	319,882	47.3	251,721	251,721	38.5	2,155,491
Ohio	7,670,815				1,268,672	1,268,672	14.0	2,463,910	2,374,310	26.4	4,027,833
Oklahoma	4,580,670				601,196	601,196	46.4	1,732,948	1,732,948	182.0	2,246,526
Oregon	3,038,642				1,457,373	1,447,373	47.1	741,659	724,394	81.8	866,876
Pennsylvania	9,347,797				149,696	149,696	.1	1,033,171	996,289	42.3	8,201,812
Rhode Island	989,208				113,368	113,368	4.0	624,495	620,828	12.7	255,013
South Carolina	2,702,012				396,563	396,563	29.2	738,848	738,548	79.4	1,566,901
South Dakota	2,976,454	79,687	79,687	30.1	591,880	591,880	152.3	518,234	518,234	105.1	1,786,654
Tennessee	4,192,460				721,617	721,617	29.7	859,134	859,134	33.8	2,611,708
Texas	11,989,350	8,068	7,769	4.9	5,460,051	4,971,771	458.0	3,550,548	3,460,677	323.3	3,549,133
Utah	2,067,154	51,885	51,885		648,832	626,014	61.4	344,629	327,245	27.3	1,062,009
Vermont	924,306				329,989	324,689	8.6	521,745	464,004	11.2	135,613
Virginia	3,652,667	49,453	49,453	45.8	1,072,429	1,072,429	551.4	847,286	847,286	230.5	1,683,500
Washington	3,026,161	696	696	.1	1,902,513	1,772,571	98.7	851,457	756,123	44.8	496,771
West Virginia	2,231,412				574,968	574,968	30.3	689,290	689,290	20.4	967,154
Wisconsin	4,823,884	60,230	50,000	1.3	1,510,626	1,296,346	68.3	2,578,769	2,395,365	197.0	1,082,174
Wyoming	2,219,155				1,010,633	1,010,628	52.6	706,069	706,061	60.8	502,466
District of Columbia	949,496	259,904	259,904	2.1	499,239	475,209	4.0	100,458	100,458	1.5	113,925
Hawaii	926,033				467,808	451,279	5.9	190,846	189,483	3.0	285,271
TOTALS	195,000,000	1,415,790	1,403,784	255.0	61,096,633	59,618,473	4,234.5	54,026,559	51,988,480	4,199.2	81,989,263

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF FEBRUARY 29, 1936

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Fund	NUMBER		
				Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise	
Alabama	$ 4,034,617					$ 1,832,926	$ 1,832,926	22		$ 1,710,621	$ 1,710,621	12	5	$ 491,070
Arizona	1,256,099					671,074	517,320	6		18,841	18,841			719,937
Arkansas	3,574,060					620,759	618,306	17		1,172,954	1,170,585	23		1,785,169
California	7,486,362					5,540,497	5,303,044	32		453,611	449,137	3		1,734,181
Colorado	2,631,567					878,180	857,180	16		237,525	237,525	2		1,536,862
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					1,062,271	1,060,541	9		324,779	324,779	4		1,442,563
Georgia	4,895,949									162,089	162,089	4		4,733,860
Idaho	1,674,479					622,844	622,844	11		200,738	160,575	1		891,059
Illinois	10,307,184					962,723	962,723	6		2,740,904	2,740,904	36		6,603,557
Indiana	5,111,096					1,514,881	1,514,881	10		1,469,075	1,469,075	10		2,127,140
Iowa	5,600,679	$ 7,303	$ 7,000	1		757,084	725,950	11		902,432	861,900	22		4,005,829
Kansas	5,246,258					468,857	468,857	4		3,747,895	3,747,895	39	1	1,029,506
Kentucky	3,672,387					559,534	531,721	6		2,042,694	1,517,666	13		1,623,000
Louisiana	3,213,467									1,294,380	1,026,000	13		2,187,467
Maine	1,426,861					223,011	222,677	4		293,806	293,806	5		910,378
Maryland	2,061,751									1,007,064	984,595	7		1,077,155
Massachusetts	4,210,833					676,151	676,151	3		329,368	329,368	3		3,205,314
Michigan	6,765,197					2,857,252	2,857,252	29		2,414,350	2,414,350	12		1,493,595
Minnesota	5,395,441	103,407	103,407	2		471,712	465,662	6		383,755	383,755	11	1	4,442,618
Mississippi	3,241,475					507,884	507,884	14		1,021,396	1,021,396	15		1,712,195
Missouri	6,142,153					226,838	226,838	3		2,071,417	2,071,417	10		3,843,898
Montana	2,722,327					1,679,800	1,679,800	30		493,437	493,437	7		549,090
Nebraska	3,556,441					880,332	880,332	26		1,078,215	1,078,215	35		1,597,894
Nevada	887,260					306,096	306,096	7		13,308	13,308			567,856
New Hampshire	822,484					140,766	140,766			81,765	81,765			599,953
New Jersey	3,983,826									693,642	693,642	4		3,290,184
New Mexico	1,725,286					414,122	414,122	5		422,145	399,901	5		911,264
New York	13,577,189					3,200,210	3,096,910	8		2,797,610	2,760,610	12		7,719,669
North Carolina	4,823,958					780,498	780,498	7		436,156	436,156	7		3,607,304
North Dakota	3,207,473					139,213	139,213	3		91,932	91,932	2		2,976,328
Ohio	8,439,897					126,598	126,598			254,100	244,100	4		8,069,199
Oklahoma	5,004,711					834,620	834,620	15		804,608	799,578	15		3,370,514
Oregon	2,334,204					809,380	807,714	7		644,464	644,464	5		882,026
Pennsylvania	11,483,613					219,670	203,527	5		1,109,458	1,064,958	18		10,215,128
Rhode Island	699,691					236,879	236,879			457,910	419,691	4		43,121
South Carolina	3,059,956					444,976	444,976	9		617,402	617,334	18		1,997,646
South Dakota	3,249,086					175,596	175,596	4		223,099	223,099	2		2,850,391
Tennessee	3,903,979					165,074	165,074	2		222,672	222,672	4		3,516,233
Texas	10,855,982	9,076	9,076	1		634,332	634,332	13		4,091,305	3,406,473	44		6,806,101
Utah	1,230,763					162,902	162,902	1		349,742	296,674	6		771,187
Vermont	729,857					351,069	349,711	4		161,254	161,254	5		218,892
Virginia	3,774,287					224,389	224,389	4		191,744	191,744	7		3,358,154
Washington	3,095,041					1,376,035	1,371,235	16		350,008	350,008	3		1,373,798
West Virginia	2,677,937													2,677,937
Wisconsin	5,022,683					1,357,726	1,294,991	13		1,073,428	1,073,428	11		2,654,264
Wyoming	1,360,841					55,366	55,365	2		20,412	20,412			1,285,064
District of Columbia	410,804					166,697	166,697	2						244,107
Hawaii	453,703					173,742	173,742	2		141,131	141,131	1		138,830
TOTALS	196,000,000	119,786	119,483	4		35,510,566	34,838,842	394		40,820,641	39,022,265	464	7	122,019,410

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1932. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933.

Report of the Chief of the Bureau of Public Roads, 1934.

Report of the Chief of the Bureau of Public Roads, 1935.

DEPARTMENT BULLETINS

No. 347D . .	Methods for the Determination of the Physical Properties of Road-Building Rock. 10 cents.
No. 583D . .	Reports on Experimental Convict Road Camp. Fulton County, Ga. 25 cents.
No. 1279D . .	Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.

TECHNICAL BULLETINS

No. 55T . .	Highway Bridge Surveys. 20 cents.
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MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

MISCELLANEOUS PUBLICATIONS.—Cont.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

No. 191 . . . . Roadside Improvement. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF FEBRUARY 29, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Fund	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Work Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,045,683	$ 8,136,887	$ 2,583,365	729.1	$ 1,176,255	$ 186,798	$ 934,658	44.2		$ 353,398	3.1	$ 46,446	$ 335,422
Arizona	5,211,960	2,641,935	8,679,591	5,206,724	2,386,912	540.6	254,875		170,167	3		22,514		3,236	62,321
Arkansas	6,748,335	3,428,049	10,172,613	6,547,823	2,652,050	569.7	640,657	80,706	558,509	32.6	$ 628	164,278	17.4	119,178	53,212
California	15,607,354	7,932,206	27,607,317	15,601,832	6,217,972	751.8	2,711,594		1,563,045	21.7		127,482	.2	5,522	23,707
Colorado	6,874,530	3,486,006	11,132,624	6,831,431	3,452,626	636.4	5,012		5,012					43,099	28,368
Connecticut	2,865,740	1,454,868	4,182,222	2,825,079	941,105	69.2	359,166		343,645	3.7		88,859	1.0	40,661	81,258
Delaware	1,819,038	923,395	2,645,646	1,819,038	782,660	128.2	32,528		32,528						108,207
Florida	5,231,834	2,661,343	8,231,537	5,188,636	1,836,663	281.5	635,958		554,003	25.6		185,299	2.5	43,198	85,378
Georgia	10,091,185	5,113,491	11,772,149	9,085,816	2,240,596	673.9	1,497,125	458,333	910,769	69.4	257,556	727,936	65.0	289,481	1,154,190
Idaho	4,486,249	2,277,436	6,201,261	4,394,175	1,404,209	486.7	749,957		748,707	9.9	69,759	63,355	2.9	32,315	61,215
Illinois	17,570,770	8,921,401	21,273,789	15,673,445	5,023,137	605.1	5,126,617	1,827,177	3,273,908	89.6	3,638	333,317		66,311	286,039
Indiana	10,037,843	5,088,963	12,806,330	9,412,488	2,860,958	389.8	2,306,108	435,020	1,836,585	95.9	63,909	330,150	2.3	126,366	61,271
Iowa	10,055,660	5,118,361	15,220,921	9,939,405	4,686,934	1,214.2	297,801	114,154	162,100	4.8		226,800	5.0	2,101	42,527
Kansas	10,039,604	5,117,675	14,161,146	9,961,286	3,808,264	1,070.1	1,327,587	39,153	1,288,434	62.2	68,553	13,352	2.2	20,611	7,625
Kentucky	7,517,359	3,818,311	10,646,935	6,981,045	2,931,863	760.4	1,086,836	432,327	572,873	44.8	55,381	129,854	7.6	48,606	133,721
Louisiana	5,828,591	2,963,932	7,783,356	5,153,539	2,013,142	213.4	1,163,590	608,534	555,006	34.1	10,666	165,106	2.9	55,802	225,678
Maine	3,369,917	1,711,586	4,918,915	3,342,536	1,374,521	184.8	286,379		286,364	8.3				27,381	50,701
Maryland	3,564,527	1,810,058	4,304,695	2,786,846	598/390	113.3	1,163,202	706,935	450,722	31.3		232,489	7.1	70,745	527,858
Massachusetts	6,597,100	3,350,474	7,007,820	4,587,052	1,833,767	104.3	3,148,543	1,974,333	1,174,210	11.0				35,715	342,497
Michigan	12,736,227	6,452,568	18,032,304	12,544,952	4,468,553	673.1	2,143,975	163,400	1,922,538	95.7		30,825	.1	27,875	30,592
Minnesota	10,656,569	5,425,551	15,381,107	9,883,265	4,774,414	1,624.1	845,761	646,206	188,445	25.9	7,266	189,542	1.8	119,838	273,150
Mississippi	6,978,675	3,540,227	10,326,747	5,996,359	1,654,691	598.0	2,460,554	860,229	1,374,620	122.2	466	424,457	26.3	121,622	86,459
Missouri	12,180,306	6,173,740	14,948,147	10,885,170	3,122,158	1,350.3	4,343,218	1,165,562	2,864,295	100.7		125,872	.4	109,574	36,815
Montana	7,439,748	3,769,734	11,027,593	7,179,659	3,196,815	1,006.2	614,655	159,632	455,023	24.8				100,457	117,896
Nebraska	7,828,961	3,964,364	12,368,929	7,730,625	3,377,119	992.1	732,366	35,778	457,313	42.0		120,283	9.2	62,559	9,648
Nevada	4,545,917	2,302,356	6,682,846	4,431,366	1,950,269	736.0	355,003	26,150	292,747	21.7		23,629		28,401	35,711
New Hampshire	1,909,839	969,462	2,939,612	1,909,443	905,742	77.2	28,026		28,026	.5		5,000		396	30,694
New Jersey	6,346,039	3,220,879	6,832,962	6,061,676	473,165	74.9	2,751,538	175,941	2,258,664	12.4				168,421	489,050
New Mexico	5,792,935	2,941,700	8,501,231	5,632,432	2,663,078	766.2	151,695		151,645	1.1	114	4,648		160,389	122,280
New York	22,330,101	11,327,921	37,237,553	21,605,913	9,116,596	799.8	3,116,050	503,720	2,063,799	25.0	75,977	70,200	.9	144,511	77,326
North Carolina	9,522,293	4,840,941	14,243,087	9,048,146	3,979,900	1,320.3	742,808	146,303	579,510	21.6	1,503	208,644	4.3	326,341	72,787
North Dakota	5,804,448	2,938,967	7,295,618	5,497,567	1,150,255	1,949.5	789,722	130,778	600,349	112.4	67,289	493,179	66.7	108,314	695,184
Ohio	15,484,592	7,865,012	22,531,139	15,277,147	5,585,378	748.8	2,240,266	158,521	1,976,366	35.1		67,558	10.8	48,924	235,710
Oklahoma	9,216,798	4,685,180	13,093,192	9,055,703	3,116,435	766.7	1,329,166	147,071	1,180,359	37.9		147,576	1.6	14,023	240,809
Oregon	6,106,896	3,097,814	9,490,294	5,956,043	2,669,034	461.8	323,223	30,834	264,264	3.6	53,042	17,837	2.9	66,378	146,679
Pennsylvania	18,891,004	9,590,788	27,262,251	17,884,019	8,122,157	981.5	1,597,854	736,539	775,268	76.8	5,126	307,671	2.1	265,320	385,691
Rhode Island	1,998,708	1,014,572	2,958,197	1,998,708	853,971	88.0	138,587		137,102	1.1		880			22,619
South Carolina	5,459,165	2,770,954	6,977,330	5,259,226	1,545,838	576.9	843,556	32,110	769,487	41.4	11,220	19,503	.2	156,609	436,126
South Dakota	6,011,479	3,047,643	8,525,798	5,773,385	2,198,377	1,471.1	484,072	15,396	468,676	52.8	69,251	273,533	27.9	153,447	107,057
Tennessee	8,492,619	4,302,991	12,075,413	8,183,983	3,022,867	461.8	1,229,327	307,391	825,535	22.3		267,474	8.9	1,245	187,115
Texas	24,244,024	12,291,253	33,655,585	23,367,015	8,715,836	2,680.0	4,501,523	829,368	3,443,215	97.8	1,557	21,558	14.5	46,104	110,644
Utah	4,194,708	2,132,691	6,936,503	4,156,356	1,862,147	584.0	357,904	6,060	267,131	6.9		1,500		32,291	1,853
Vermont	1,867,573	948,007	3,038,539	1,863,531	845,644	137.6	109,059	3,922	90,873	2.4				121	11,489
Virginia	7,416,757	3,765,387	11,225,077	7,171,544	3,134,345	573.0	463,452	91,148	364,960	44.1	104,641	51,381	3.5	49,523	214,701
Washington	6,115,867	3,106,412	8,769,969	6,101,000	2,449,790	291.0	639,072		632,975	11.8		1,727		14,867	21,920
West Virginia	4,474,234	2,280,335	5,411,399	4,242,219	988,925	186.5	1,134,352	199,016	881,403	31.9		147,956	4.0	32,999	262,051
Wisconsin	9,724,881	4,941,837	14,826,227	9,626,072	4,299,948	604.7	572,508	7,300	522,766	15.3		97,591		91,509	21,533
Wyoming	4,501,327	2,287,712	6,667,080	4,473,877	2,053,207	1,008.5	223,172	46,705	149,732	28.8		47,239		20,745	37,535
District of Columbia	1,918,469	973,842	2,570,032	1,909,584	660,313	19.5	313,125		277,625	2.9				8,885	35,904
Hawaii	1,871,062	949,778	1,496,428	1,122,101		32.2	1,500,112	740,221	562,704	20.4		353,640	3.0	8,740	33,434
TOTALS	394,000,000	200,000,000	566,113,389	375,265,219	142,594,701	33,165.8	61,015,491	14,248,801	42,404,550	1,733.7	918,276	6,689,092	308.3	3,567,704	8,311,657

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Volume 17, No. 2 April 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

THE NEW HAMPSHIRE FINANCIAL SURVEY

DIGEST OF A SURVEY OF THE FINANCES OF NEW HAMPSHIRE IN 1932, WITH SPECIAL REFERENCE TO HIGHWAYS, CONDUCTED BY THE BUREAU OF PUBLIC ROADS AND THE UNIVERSITY OF WISCONSIN

Reported by **ELIZABETH CHURCH**, Assistant Research Analyst, Division of Highway Transport, Bureau of Public Roads

THE NEW HAMPSHIRE financial survey is one of a series of studies in highway finance sponsored by the United States Bureau of Public Roads in cooperation with the University of Wisconsin and the highway department in each of the States studied.[1]

The survey covers for the year 1932 the financial transactions of the State of New Hampshire and its political subdivisions, with special emphasis upon highways. Space does not permit giving much explanatory data and descriptions, so where factual material in tables can be readily understood without additional interpretation, comments have been omitted. An effort has been made to include all of the salient material and to discuss adequately the important problems and conditions pertaining to New Hampshire highways. For greater ease of comparison the arrangement of material follows that of previous summaries.[2]

The two primary objectives of the survey were: (1) To ascertain the fiscal relation of highways to all other fiscal affairs of the community; and (2) to show facts pertaining particularly to highways, such as highway classifications, mileage and surfacing, expenditures for maintenance, construction, and overhead, and the sources of funds necessary to defray the costs, both by types of imposts and by the locality providing them.

CLASSIFICATION OF PRIMARY ROUTES

Probably the most important facts concerning New Hampshire highways are those pertaining to the administration of the primary roads and the results obtained under the State-aid plan. In addition, attention is called to the increase in efficiency and economy that might result through consolidation of local road operations, the advantages accruing through a closer connection between the State highway department and localities, both in the furnishing of engineering services and the approval of certain construction projects, and the need for the codification of the highway statutes.

The present system of administering the primary highway system is confusing. The legally designated trunk lines comprise a major part of the primary system, but they do not include all of the numbered routes. The primary system, therefore, is administered under several different statutory provisions.

The traveled primary system of New Hampshire at the present time comprises some 1,809 miles of numbered through routes. Of this total, 1,517 miles are trunk-line mileage as officially designated by the legislature, 90 miles are State roads on the numbered system, and the remaining 202 miles are State-aid highways. This difference is one of technical terminology only, however.

Of the 1,517 miles of official trunk-line highways, 1,456 miles comprise the official trunk-line system financed by the State and administered by the State highway department under special laws applying only to the trunk lines. The remaining 61 miles are within city limits, are under municipal control, and are financed by the municipality through which they pass. The 90 miles of State roads upon the numbered system are also financed by the State and administered by the highway department, but under statutory provisions other than those covering the officially designated trunk lines. The State, therefore, has complete jurisdiction over only 1,546 miles of the numbered highway routes.

The variety of classifications on the numbered primary routes resulted from the piecemeal enactment of trunk-line highway legislation only as necessity demanded. The State-aid plan was designed to create through routes but failed to accomplish this purpose. Certain towns failed or refused to cooperate, leaving gaps in the planned through system and thus defeating the intent of the plan. As a remedy, special laws were then passed designating specific roads as trunk-line routes and prescribing special methods for financing and administration, still based to some extent, however, upon the standard State-aid plan. Bit by bit additional mileages were added and new laws enacted until the present status was evolved.

The primary system, therefore, is administered under several different statutory provisions. If the legally designated trunk-line system and the numbered system of through routes were made coextensive and placed completely under State control, financial responsibility would be centralized, administration simplified, and confusion eliminated.

Although the established practice of designating highways by a number and keying the number to a map is used in New Hampshire, it has no legislative sanction. Each of the trunk routes is described in the laws by a name, such as the "Daniel Webster Highway." Some qualified body could be authorized to designate officially the principal routes by numbers. If a secondary system were established, symbols could be used to distinguish the systems.

At present State laws do not permit the expenditure of State funds for highways in compact areas of 2,500 persons or over, yet the urban portions of the trunk highways must be adequate to serve the through traffic upon them.

The State-aid roads are primarily local rural roads which the State helps support through the allocation to local communities of part of the State motor-vehicle revenues. The funds are allocated in proportion to local taxation. Organized planning is extremely difficult because of the large number of local governmental units. Although the revenues for the State's participation are derived from highway users, no system of roads serving State-wide traffic and coordinated with the primary routes has been developed. A secondary highway system could readily be developed, however, using a considerable mileage of the present State-aid roads as a basis.

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[1] The investigation was made in 1934 under the immediate direction of Dr. Henry R. Trumbower, professor of economics at the University of Wisconsin and economist for the Bureau of Public Roads, and H. R. Briggs, field investigator and statistician.

[2] For results of the Wisconsin, Michigan, Illinois, and Minnesota surveys, see the April 1933, June 1933, May 1933, and March 1936 issues of PUBLIC ROADS.

The present system of having the local town road maintenance under the supervision of over 500 different road agencies is expensive and relatively inefficient. There is extreme variation between towns in the average maintenance costs per mile on the local rural roads. This is due, among other causes, to low standards of maintenance, lack of funds and equipment, and lack of supervision and efficient advisory services.

The creation of a permanent patrol system with full-time road workers and a system of road districts would promote efficiency and economy. The creation of road districts comprising territorial areas larger than individual towns or having the work done by the divisions of the State highway department under contractual arrangements would accomplish these ends.

Expensive reconstruction costs could be avoided if it were required that construction projects upon local roads involving an expenditure of $2,000 or more and every bridge constructed be approved by the State highway department before work is undertaken.

For the making of plans and all other services connected with the development of local roads, the staff of the highway department could continue to be available to give such assistance as might be required. Whether or not the highway department should be compensated for services other than those of a purely advisory nature is a matter of State policy. Probably the present system of charging a moderate fee for the work done is the most equitable plan.

In the existing statutes there are duplications, conflicts, and apparently obsolete or unenforced provisions. These conditions could be corrected by a codification of the highway laws and the repeal of undesired and unenforced statutes. Additional legislation is needed to revise and simplify the highway classifications.

GENERAL CHARACTERISTICS OF STATE

Many local factors have influenced the development of the highway system in New Hampshire. Large areas of the State are of little economic value; consequently, the revenues of the State and, therefore, the amounts available for highways are limited. The mountains affect highway locations and costs. The industrial centers that have grown up around water-power development projects have further influenced the highway routing. Since there is heavy tourist traffic in the State, the providing of adequate highway facilities for this travel has been important.

Because at present all parts of the State are within a reasonable distance of some suitable road-building material, local costs are quite comparable. In some localities, however, these deposits of materials will soon be exhausted. In such places the additional cost of transporting materials longer distances will then have to be met.

There are 10 counties in New Hampshire, subdivided into 224 organized towns and 11 incorporated cities. The towns are similar in size and political organization to the townships in the States outside of New England. The towns are further subdivided into precincts and school districts, not necessarily coextensive. Manchester, with a population of 76,834, is the largest city. The total population of the State in 1930 was 465,293, of which 345,034 were in urban communities and 120,259, or almost 26 percent, in rural areas—the noncompact areas of towns or cities.

The assessed valuation of all taxable property in New Hampshire in 1932 was $623,381,900. Twenty-nine percent of this total, or $183,277,600, was in rural areas. In Manchester alone there was $106,151,900 worth of taxable property, or 17 percent of the total property valuation in the State. Almost 56 percent of the total valuation was concentrated in the southeastern part of the State. This portion of New Hampshire is its largest manufacturing area and contains 9 of the State's 11 incorporated cities. The entire northern half of the State had but one-fourth of the total assessed valuation of the State.

PLAN OF STUDY OUTLINED

For purposes of analysis and presentation, financial data must be set up on comparable bases. It is necessary to show the proper division of the financial data for the various civil subdivisions, to give the proper analysis of data relative to incorporated cities, and to present all the data for all subdivisions of the State by some convenient division.

Since the 10 counties of the State are unimportant as governmental agencies, county units were disregarded except insofar as financial statistics were properly allocated between the governmental units comprising each.

In the financial surveys conducted by the Bureau the statutory designations of governmental units smaller than the counties have been ignored because of the varying concepts applying to the same term. Data are shown instead for rural areas and urban communities, the latter according to population. In New Hampshire grouped the statutory classification of an area as a town or a city does not signify that the area is rural or urban in its characteristics. The statutory town in New Hampshire may include urban communities, while the statutory city may have extensive rural areas within its limits. Since a classification was essential for this survey, it was necessary to determine by field investigation the urban and rural populations of the various towns in the State and the size of those communities. In all the towns a subdivision was made between the compact areas definitely urban in character and the rural sections. The division into classes of residence is as follows:

1. Rural areas outside of any settlements or communities.
2. Urban places having a population to 2,499.
3. Urban places having a population of 2,500 to 14,999.
4. Urban places having a population of 15,000 to 74,999.
5. Urban places having a population of 75,000 to 399,999.

Manchester is the only place in New Hampshire having a population over 75,000.

Since all taxes are levied by the public acts of governmental agencies, it is necessary to know which agency initiates the tax. The first classification of imposts is by type of revenue, listed by the public agency responsible for its imposition. Such a tabulation shows the total public imposts levied by each governmental unit according to type of impost. The second classification is by incidence of impost and shows the communities responsible for paying the tax. The local communities carry on their own government, raise their own revenues, and make their own disbursements. In addition, however, the counties and State perform functions for the benefit of these local areas. For these activities the State and counties levy imposts

Highways in New Hampshire.

against the property and inhabitants of local areas. Thus, communities have their own local taxes and also imposts that they must pay to larger governmental units. Therefore, to classify taxes according to incidence, both local and other charges must be allocated and the total for which each community is responsible must be shown. So far as possible, all imposts are further subdivided as to the purpose for which they are levied. They are divided into levies for four purposes—highways and streets, education, public benefit, and government.

The main considerations in classifying expenditures are the units of government originally making them and the determination of the place where they are finally made. Besides the local expenditures, it is necessary to take into consideration the expenditures made by the larger units of government in the various minor governmental units for the benefit of the persons and property in those local communities. The final comparison, then, is based on the local expenditures plus the expenditures made by the State and the county in or for each community.

The outstanding indebtedness is first classified by the unit of government incurring it. The debts are also subdivided by the purposes for which they were incurred. Debt service is classified by purpose only. Partial allocation of the debt service by units of government and by rural or urban areas is made in the expenditure classification where interest payments are included.

SOURCES OF MATERIAL

For proper interpretation of the data obtained in this survey, a brief description of the methods employed is necessary. Analogous procedures were followed in the financial surveys made by the Bureau in other States.

Because governmental financial records are kept from the accounting standpoint to reflect financial transactions with specific funds they are not readily adaptable to statistical purposes. The numerous transfers, different concepts of public functions, and different methods of handling funds in various communities almost always require a careful analysis and reassembly of all public financial data if factual results are to be obtained.

In no case were totals for tax levies, expenditures, debts, road mileages, or any other facts, taken from previous compilations or reports. The original data were collected and analyzed, and from them the needed facts were extracted without omission or duplication. A complete financial analysis involves finding the data for public utilities, special assessment districts, special districts, and municipalities, and combining these to obtain the total of all local receipts, debts, and expenditures. To these are added the proper allocation of similar data for the State and counties, thus obtaining a complete analysis of the receipts, expenditures, and debts of the rural and urban areas of the State.

Two special problems were encountered in the tax analysis. The first of these was due to the fact that while each agency has its own specific taxes, there are a number of taxes that are levied or collected jointly. These have been treated as joint State and local imposts.

The second problem is more important. In New Hampshire, a tax levy is different from the tax actually imposed. This is true because of the method of using the property tax as a balancing item to provide needed funds. The total of all public receipts other than property taxes are subtracted from the total budgetary requirements. The additional sum required is submitted to the collector to be extended against the property in the community. For example, the State property tax was $1,400,000 and each town and city was charged with its portion of this tax based upon its valuation as fixed by the tax commission. However, the State as agent collects certain taxes for all the towns. Instead of remitting these receipts, the State offsets the amounts received for each town against the property tax for the town and only the difference is charged to the town for collection. Hence the property tax levied against a town is no measure of the impost of that nature that it will actually pay.

The same procedure is followed in the towns. The town levies the State property tax eventually charged against it, the county property tax, and other property taxes at specified rates for roads, schools, and other purposes. These are totaled and constitute the theoretical property tax levy. From this total all the other town receipts are subtracted and the remainder is spread against the taxable property as the actual property tax.

In New Hampshire there are three major imposts on all motor vehicles: The State registration fee, the gasoline tax, and the local permit fee charged in lieu of local personal property taxes. The problem presented itself of subdividing the data pertaining to each of these motor-vehicle imposts between the rural areas and the four classes of urban communities. No data were available for making such divisions for any of these three imposts. The same procedure, therefore, was followed that has been used successfully in other States for making such allocations. On the basis of the tabulation and analysis of a large representative sample of license fees paid, the allocation of the total amount received from registration fees was made. Questionnaires were sent to motor-vehicle owners to ascertain the gasoline tax paid by the residents in the several classes of places. In all studies it has been possible to determine the accuracy of the sample by several statistical checks. The information pertaining to highway classifications, mileages, and surfaces was obtained from the State highway department.

The material presented in this and previous Bureau studies of New Hampshire was obtained from the same sources. However, this study was conducted on an entirely different basis from any previous Bureau survey of the State, so differences in final results were anticipated. It has been possible to make reconciliations to these other reports.

DEFINITION OF TERMS

For uniformity the following definitions are basic in all the surveys:

Highway includes all items having to do with the construction, maintenance, marking, erection of signs, and administration of all highways, streets, and alleys. Street cleaning and street lighting are not included.

Education consists of all items having to do with the construction, maintenance, teaching, and administration of all public schools and libraries.

Public benefit consists of all items having to do with the protection of lives and property, and the pleasure or well-being of the people, including police and fire protection, courts, sanitation, parks and playgrounds, and charitable and penal institutions.

Government consists of all items having to do with the general administration of public affairs not allocable to one of the three preceding public purposes. These are primarily the executive and administrative functions of government.

Expenditure means public costs defrayed out of public revenues. The net cost is shown, not the gross amount. The net expenditure is the total expenditure less the earnings made by the public service charged with the costs. For example, the cost of prisons is the total expenditure less the earnings from prison industries.

Imposts include every payment of any nature made to a public body occurring because of or in connection with the authority vested within it. Thus, all licenses, fees, permits, special assessments, and taxes proper are shown as imposts.

User revenues are imposts in the form of vehicle licenses, gasoline taxes, and allied charges paid by the operators of motor vehicles.

There is great variety in the dates of the fiscal years used by governmental agencies in New Hampshire. The State government and school districts have their fiscal years ending June 30; the counties use December 31; towns and villages use January 31; and cities use various dates from November 30 to February 28. Data are shown in this report for the calendar year 1932. In cases where the calendar and fiscal years did not coincide, slight adjustments were made to obtain comparable statistics.

NEW HAMPSHIRE HIGHWAY SYSTEM

New Hampshire laws and reports show six statutory classifications of highways as follows:

Class 1 roads include the officially designated State trunk-line highways and other State roads, all completely under State control. These roads include 1,456 miles of designated State trunk-line highways, 90 miles of State numbered routes not on the trunk-line system, and 50 miles of other State highways in mountainous and thinly settled areas, making a total of 1,596 miles of class 1 roads.

Class 2 roads include the State-aid roads, that are roads under joint State and local jurisdiction. This class comprises 1,235 miles of local roads and 202 miles of roads on the State numbered highway system, making a total of 1,437 miles.

Class 3 roads are the uncompleted sections of the State trunk-line highway system. As the trunk-line highway system has been completed, there are no roads of this statutory classification.

Class 4 roads are streets in compact areas, and are under local control. There are 61 miles of urban streets forming a part of the designated trunk-line highway system, and 500 miles of other urban streets, making a total of 561 miles of class 4 roads.

Class 5 roads are the local town roads under local control. There are 8,717 miles of these local town roads.

Class 6 roads are abandoned roads. For the purposes of this report this class of roads has no significance.

The State numbered primary highway system of 1,809 miles consists of: Designated State trunk roads completely under State control, 1,456 miles; roads completely under State control but not on the trunk-line highway system, 90 miles; streets that are in compact areas and completely under local control, 61 miles; and State-aid roads that are under joint State and local control, 202 miles.

Thus there is an overlapping of the roads as grouped by statutory designation and by administrative control.

In 1932 there were 12,311 miles of roads and streets in New Hampshire. Of this total 11,750 miles, or 95.4 percent, were highways outside of compact areas. Table 1 and figure 1 show that over 70 percent of the rural roads of the State in 1932 were unsurfaced. Over 8,200 miles, or 94 percent, of the local town roads were earth. All of the State and State-aid roads were surfaced. The State and State-aid roads were mainly of a low-type surfacing, however, and less than 4 percent of the rural highways of the State had a concrete or other high-type surfacing. No data were collected as to the types of surfacing on the streets in compact areas (class 4 roads).

Almost three-fourths of the rural highways in New Hampshire are local town roads. The State highway department has control over the administration and financing of 25.8 percent of the rural highways. There are no county roads, nor does the county spend anything for highways.

NEW HAMPSHIRE TAXES IN 1932

Total taxes and imposts levied for all purposes in New Hampshire in 1932 were $27,089,600. Taxation of general property totaled $16,342,900, or 60.3 percent; imposts paid by motor-vehicle owners, $5,270,000, or 19.5 percent; other revenues, consisting of insurance, inheritance, utility and savings-bank taxes, and miscellaneous State and local imposts, $5,476,700, or 20.2 percent.

Of the total taxes and imposts levied, rural taxpayers paid $6,769,900, or 25 percent; those in incorporated places having a population to 2,499, $4,559,400, or 16.8 percent; in places of 2,500 to 14,999 population, $6,459,400, or 23.8 percent; in places of 15,000 to 74,999 population, $4,509,400, or 16.7 percent; in Manchester, $4,301,100, or 15.9 percent; and nonresidents paid $490,400, or 1.8 percent.

The average actual tax rates on general property, per $100 valuation, were as follows: Rural areas, $2.34; incorporated places to 2,499 population, $2.76; places 2,500 to 14,999 population, $2.75; places 15,000 to 74,999 population, $2.92; and Manchester, $2.54.

Rural motor-vehicle owners paid in license fees, gasoline taxes, and miscellaneous motor-vehicle imposts an average of $42.04; residents in places to 2,499 population, $44.34; in places 2,500 to 14,999 population, $44.98; in places 15,000 to 74,999 population, $49.81; and in Manchester, $53.38.

TAXES LEVIED AND INCIDENCE OF TAXATION

Table 2 gives the total taxes levied for all purposes in New Hampshire in 1932 by the several classes of governmental units. The relative unimportance of the functions of the county in New Hampshire is apparent. It is evident that the bulk of the taxes were levied by the local communities for their own use.

All State and county imposts are ultimately paid by the taxpayers in rural and urban areas. In table 3 the State and county levies have been distributed and the amounts added to the local charges to obtain the total amounts payable by the residents in the various classes of rural and urban communities.

The revenues for all purposes were obtained from the various sources shown in table 4.

All imposts have been subdivided by governmental unit levying them, by residence of taxpayers paying them, and by type of impost. The general property tax accounted for over 60 percent of the total revenue. The motor-vehicle imposts were of next importance, $5,270,000 being obtained from these taxes. Over $490,400 of the motor-vehicle imposts was collected from nonresidents.

Table 1.—*Classification of rural highways in 1932 by official designation and by type of surfacing*

Official designation	Concrete		Bituminous macadam		Stone, gravel, etc.		Earth		Total	
	Miles	*Pct.*	*Miles*	*Pct.*	*Miles*	*Pct.*	*Miles*	*Pct.*	*Miles*	*Pct.*
Class 1 roads (State highways)	222	13.9	188	11.8	1,186	74.3	......	..	1,596	13.6
Class 2 roads (State-aid roads)	4	.3	14	1.0	1,419	98.7	......	......	1,437	12.2
Class 5 roads (local town roads)	1	....	24	.3	448	5.1	8,244	94.6	8,717	74.2
Total	227	1.9	226	1.9	3,053	26.0	8,244	70.2	11,750	100.0

Table 2.—*Distribution of all taxes levied for all purposes by the State and its subdivisions for collection in 1932*

Imposed by—	Amount	Percent	Amount per capita
State	[1] $8,425,900	31.1	$18.11
Counties	1,406,300	5.2	3.02
Rural areas	4,325,200	16.0	35.97
Places to 2,499	2,795,000	10.3	34.75
Places 2,500 to 14,999	4,148,200	15.3	37.35
Places 15,000 to 74,999	3,094,900	11.4	[illegible]
Manchester	2,894,100	10.7	37.67
Total	[1] 27,089,600	100.0	58.22

[1] Includes $490,400 of motor-vehicle charges imposed on nonresidents.

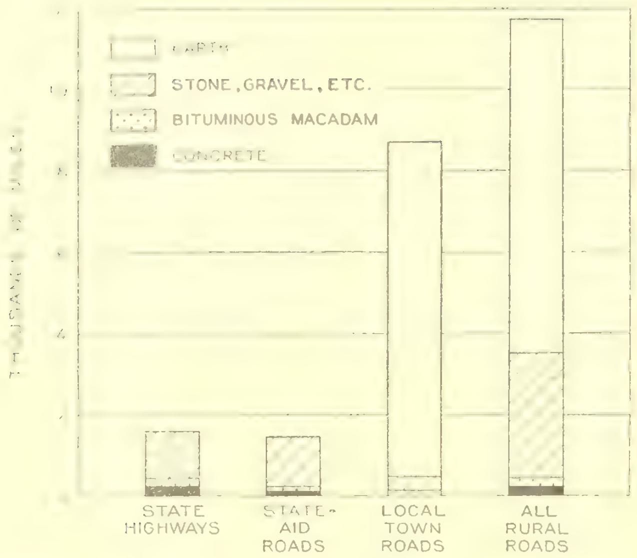

Figure 1.—Mileage of New Hampshire Rural Highways in 1932, by Types.

Table 3.—*Incidence of all State and local charges imposed in 1932*

Payable by taxpayers in—	Amount	Percent	Amount per capita
Rural areas	$6,769,900	25.4	$56.30
Places to 2,499	4,559,400	17.1	56.69
Places 2,500 to 14,999	6,459,400	24.3	58.16
Places 15,000 to 74,999	4,509,400	17.0	58.79
Manchester	4,301,100	16.2	55.98
Total	26,599,200	100.0	57.17
Nonresidents	490,400		
Grand total	27,089,600		

Table 5 is a recapitulation of table 4 and shows the liability of the residents of the various rural and urban areas for the payment of the several kinds of taxes, but it does not include the motor-vehicle imposts paid by nonresidents.

Table 6 gives, in the second column, the tax rates per $100 valuation levied upon general property in each of the several classes of local governmental units. For purposes of comparison, the third column gives the rates that would have been required if the total amount received from all taxation had been levied upon general property, and the last column gives the percentages that general property taxes were of all taxes paid by residents. Figure 2 is a graphical presentation of these data.

IMPOSTS USED FOR HIGHWAY PURPOSES

The only taxes levied specifically for highway purposes were the State motor-vehicle imposts—license fees, gasoline taxes, and miscellaneous motor-vehicle imposts—which totaled $4,757,000. The localities collected a permit fee on motor vehicles, but the proceeds from this impost went into the general community fund and only about $91,000 was used for highway purposes. These user revenues comprised $4,848,000 of funds for street and highway purposes or 59 percent of the total for such purposes.

Since the total 1932 highway program required $8,202,300, part of the revenue from the general property taxes and other imposts had to be used for highway purposes. Table 7 shows that to meet this need $2,865,800 was derived from the general property tax, and $488,500 from other revenue sources. The special assessment method of financing highways, although it is extensively used elsewhere, is not used in New Hampshire.

Nonresidents paid at least $436,000 of user revenues expended upon New Hampshire highways. The license fees and miscellaneous imposts paid by them were known. The total amount of gasoline consumed by vehicles owned by New Hampshire residents was obtained and thus the total amount of gasoline tax paid

Table 4.—*Sources of revenue by type of tax or revenue*

Type of tax	Amount	Percent	Amount per capita
General property tax	$16,342,900	60.3	$35.12
Other imposts:			
State:			
Telephone and telegraph taxes	319,200	1.2	0.69
Gas and electric company taxes	175,300	.6	.38
Inheritance tax	459,000	1.7	.99
Motor-vehicle imposts	[1] 4,757,000	17.6	10.22
Licenses, fees, permits	271,300	1.0	.58
Miscellaneous income	214,700	.8	.46
Total State	6,196,500	22.9	13.32
Joint State and local:			
Insurance taxes	442,500	1.6	.95
Savings-bank tax	636,800	2.3	1.37
Intangibles tax	586,100	2.2	1.26
Railroad tax	937,900	3.5	2.02
Building and loan association tax	1,600		
Total joint State and local	2,604,900	9.6	5.60
Local:			
Motor-vehicle permit fee	513,000	1.9	1.10
Poll tax	332,200	1.2	.72
National bank-stock tax	51,800	.2	.11
Licenses, permits, fees	101,800	.4	.22
Miscellaneous income	927,000	3.4	1.99
Total local	1,925,800	7.1	4.14
County—Miscellaneous imposts	19,500	.1	.04
Total other imposts	10,746,700	39.7	23.10
Grand total	[1] 27,089,600	100.0	58.22
RECAPITULATION			
General property taxes	16,342,900	60.3	35.12
Motor-vehicle imposts	[1] 5,270,000	19.5	11.33
Other State imposts	1,439,500	5.3	3.09
Joint State and local imposts	2,604,900	9.6	5.60
Other local imposts	1,412,800	5.2	3.04
Miscellaneous county imposts	19,500	.1	.04
Total	[1] 27,089,600	100.0	58.22

[1] Includes $490,400 of imposts charged against nonresidents.

Table 5.—*Incidence and classification of all taxes levied in 1932 and paid by residents*

Payable by taxpayers in—	General property taxes		Motor-vehicle imposts		Other taxes		All taxes	
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent
Rural areas	$4,280,400	26.2	$1,131,600	23.7	$1,357,900	24.8	$6,769,900	25.4
Places to 2,499	2,634,100	16.1	1,019,500	21.3	905,800	16.6	4,559,400	17.1
Places 2,500 to 14,999	3,815,600	23.3	1,229,600	25.7	1,414,200	25.8	6,459,400	24.3
Places 15,000 to 74,999	2,918,300	17.9	696,500	14.6	894,600	16.3	4,509,400	17.0
Manchester	2,694,500	16.5	702,400	14.7	904,200	16.5	4,301,100	16.2
Total	16,342,900	100.0	[1] 4,779,600	100.0	5,476,700	100.0	26,599,200	100.0
Percentage of all taxes		61.4		18.0		20.6		100.0

[1] Made up as follows: $2,340,600 of gasoline taxes, $1,569,500 of registration fees, $356,500 of miscellaneous imposts and $513,000 of local permit fees.

by them was determined. The balance, found by deducting the amount paid by New Hampshire residents from the total gasoline tax collected, was the amount paid by nonresidents.

TABLE 6.—*General property tax rates per $100 valuation in 1932, and their relation to the total of all imposts*

Unit of government in which taxes were payable	Actual tax rate on general property as levied [1]	Tax rate needed to raise all taxes by general property tax levies [2]	Percentage that general property taxes are of all taxes and imposts [2]
Rural areas	$2.34	$3.69	63.2
Places to 2,499	2.76	4.78	57.8
Places 2,500 to 14,999	2.75	4.65	59.1
Places 15,000 to 74,999	2.92	4.52	64.7
Manchester	2.54	4.05	62.6
Average for State	2.62	4.27	61.4

[1] Statutory standard of assessment is full value, and assessment is made substantially at that figure.
[2] Based on total, excluding $490,400 paid by nonresidents.

TABLE 7.—*Taxes from which funds were derived for highway and street purposes in 1932*

Type of tax	Amount	Percent	Amount per capita
Local general property tax	$2,865,800	34.9	$6.16
Motor-vehicle imposts:			
Road toll	[1] 2,638,800	32.2	5.67
License fees	[2] 1,723,100	21.0	3.70
Miscellaneous imposts	[3] 395,100	4.8	.85
Local permit fees	91,000	1.1	.20
Total user revenues	[4] 4,848,000	59.1	10.42
Total general property tax and user revenues	7,713,800	94.0	16.58
Other imposts [5]	488,500	6.0	1.05
Grand total	[6] 8,202,300	100.0	17.63

[1] Includes $298,200 paid by nonresidents.
[2] Includes $153,600 paid by nonresidents.
[3] Includes $38,600 paid by nonresidents.
[4] Includes $490,400 paid by nonresidents.
[5] Made up of national bank-stock tax, miscellaneous license fees and permits, poll tax, miscellaneous income and commercial revenues, insurance tax, savings-bank tax, intangibles tax, building and loan association tax, and railroad tax.
[6] This amount was needed to meet expenses of administering motor-vehicle taxes and principal payments on highway debt in addition to the amounts actually expended upon highways and streets.

The amount of imposts levied for highway and street purposes paid by the residents of the State was $7,711,900, as shown in table 8. The amount given for each class of place is the sum of all taxes imposed for highway purposes. For the urban places this included the contributions for local street improvements as well as the urban share of the rural highway program.

MOTOR-VEHICLE REGISTRATIONS, IMPOSTS, AND TRAVEL PERFORMED

Of the 104,383 motor vehicles registered in New Hampshire in 1932, 87,217, or 83.6 percent, were passenger cars.[3] This was 1 passenger car for every 5.3 persons. The ratio for trucks and busses was 1 to every 27.1 persons.

To obtain their approximate distribution between the rural areas and the several classes of urban places, a sample of the registrations was tabulated by locality. Questionnaires were then sent to those motor-vehicle owners whose locations were uncertain. Several checks made against known facts determined the accuracy of the results. Table 9 shows the distribution of motor vehicles among the several classes of places.

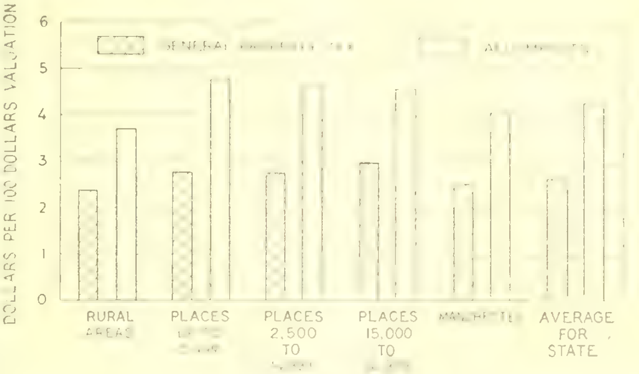

FIGURE 2.—ACTUAL TAX RATES ON GENERAL PROPERTY AND RATES REQUIRED IF ALL TAXES WERE LEVIED ON GENERAL PROPERTY.

TABLE 8.—*Incidence of taxes used for street and highway purposes in 1932, classified by places*

Payable by taxpayers in—	Amount	Percent	Amount per capita
Rural areas	$2,150,000	27.9	$17.88
Places to 2,499	1,459,800	18.9	18.15
Places 2,500 to 14,999	1,826,500	23.7	16.44
Places 15,000 to 74,999	1,162,200	15.1	15.15
Manchester	1,113,400	14.4	14.49
Total	7,711,900	100.0	16.57
Nonresidents	490,400		
Grand total	8,202,300		

Registration fees collected from motor-vehicle owners in New Hampshire are based upon the weight of the vehicle. New Hampshire residents in 1932 paid $1,569,500 in motor-vehicle license fees, an average of $15.04 per vehicle. Owners of trucks and busses paid an average fee of $25.04 and passenger-car owners paid $13.07. Nonresident registration fees totaled $153,600, about 9 percent of the total of $1,723,100 received from license fees. The total and average amounts paid by the owners in the various places are shown in table 9. The highest average passenger-car and truck fees were paid by motor-vehicle owners in the largest cities, and the lowest were paid by motor-vehicle owners in the rural areas. These deviations are normal, for the most valuable and heaviest passenger cars and trucks are usually found in urban areas.

The cost of collecting the motor-vehicle license fees was approximately $77,000, or 4.9 percent of the total gross revenue, making a cost of 74 cents per vehicle. This was the cost of licensing and all allied activities.

DISTRIBUTION OF TRAVEL PERFORMED AND GASOLINE CONSUMPTION DETERMINED BY QUESTIONNAIRES

As in the other States studied, questionnaires were sent to a representative sample of the motor-vehicle owners of the State to determine the amount of gasoline consumed and the number of miles traveled during the year. The results obtained by these questionnaires are shown in table 10. Of all vehicles in the various classes of places, those in the rural areas traveled the least, averaging 6,836 miles annually, while the vehicles in Manchester traveled the most, averaging 8,679 miles. Trucks and busses traveled, on an average, about 10 percent more than passenger cars.

Table 10 also shows that the average annual gasoline consumption per vehicle by trucks and busses was

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[3] These figures exclude nonresident registrations and are therefore somewhat smaller than figures previously issued by the Bureau.

Figure 3.—Total Travel Performed by Passenger Cars and Trucks and Busses in 1932, Distributed by Place of Ownership.

Table 9.—*Motor-vehicle registrations, persons per vehicle, and registration fees paid, distributed by place of ownership among the several classes of local governmental units*

Place of ownership	Registrations		Persons per vehicle	Registration fees		
	Number	Percent		Amount	Percent	Amount per vehicle
Rural areas:						
Passenger cars	21,811	[1] 25.0	5.5	$274,200	[1] 24.1	$12.57
Trucks and busses	5,100	[2] 29.7	23.6	108,300	[2] 25.2	21.24
Total	26,911	25.8	[illegible]	382,500	24.4	14.21
Places to 2,499:						
Passenger cars	19,140	[1] 21.9	4.2	251,200	[1] 22.0	13.12
Trucks and busses	3,852	[2] 22.4	20.9	90,500	[2] 21.1	23.49
Total	22,992	22.0	3.5	341,700	21.8	14.86
Places 2,500 to 14,999:						
Passenger cars	23,159	[1] 26.6	4.8	305,700	[1] 26.8	13.20
Trucks and busses	[illegible]	[illegible]	26.6	116,100	[2] 27.0	27.78
Total	27,338	26.2	4.1	421,800	26.9	15.43
Places 15,000 to 74,999:						
Passenger cars	11,849	[illegible]	6.5	160,300	[1] 14.1	13.53
Trucks and busses	2,134	[2] 12.4	35.9	60,000	[2] 13.9	28.12
Total	13,983	13.4	5.5	220,300	14.0	15.75
Manchester:						
Passenger cars	11,258	[1] 12.9	6.8	148,300	[1] 13.0	13.17
Trucks and busses	1,901	[2] 11.1	40.4	54,900	[2] 12.8	28.88
Total	13,159	12.6	5.8	[illegible]	12.9	15.44
State totals:						
Passenger cars	87,217	83.6	[illegible]	1,139,700	72.6	13.07
Trucks and busses	17,166	16.4	27.1	429,800	27.4	25.04
Total	104,383	100.0	4.5	1,569,500	100.0	15.04

[1] Percentage of State total for passenger cars.
[2] Percentage of State total for trucks and busses.

almost 50 percent greater than the consumption per passenger car. This was caused by both the lower mileage per gallon obtained and the greater distances traveled by the trucks and busses.

Table 11 shows the total travel in vehicle-miles, and total gasoline consumption in gallons, for passenger cars and trucks and busses, distributed by place of ownership. These data were derived from the previously established data on registrations, average gasoline consumption, and average mileage traveled. Figures 3 and 4 show interesting relations regarding passenger cars and trucks and busses.

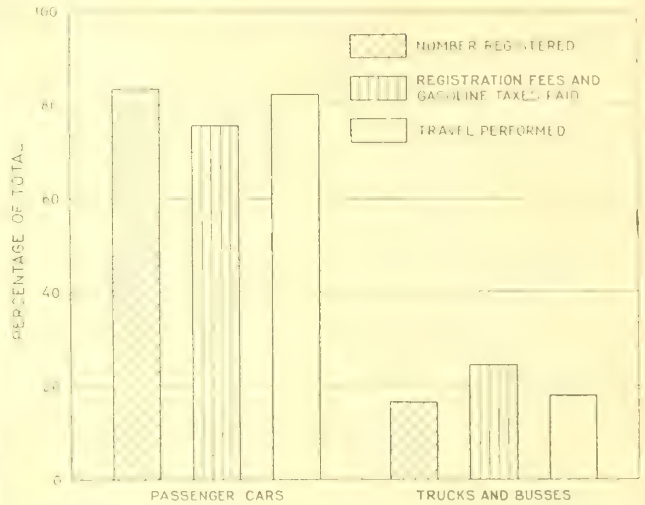

Figure 4.—Percentage Distribution of All Vehicles by Number Registered, Registration Fees and Gasoline Taxes Paid, and Travel Performed.

Table 10.—*Average mileage traveled and average gasoline consumption per motor vehicle in 1932, by place of ownership*

Place of ownership	Average gasoline consumption			Average mileage traveled		
	Passenger cars	Trucks and busses	All vehicles	Passenger cars	Trucks and busses	All vehicles
	Gallons	*Gallons*	*Gallons*	*Miles*	*Miles*	*Miles*
Rural areas	452	722	503	6,639	7,675	6,836
Places to 2,499	510	696	541	7,333	7,034	7,305
Places 2,500 to 14,999	516	727	548	7,090	8,101	7,245
Places 15,000 to 74,999	595	893	640	7,686	8,763	7,850
Manchester	606	992	662	8,402	10,321	8,679
Average	521	769	[1] 562	7,281	8,063	7,410

[1] The gasoline consumption per registered vehicle is reported in the Taxation of Motor Vehicles in 1932 as 622 gallons. In deriving this figure no allowance was made for gasoline consumed by tourists. New Hampshire has a large amount of summer tourist travel. The proportion of gasoline consumed by out-of-State cars is increased by the light winter travel by all classes of traffic.

From tables 9 and 11, a comparison can be made between the distribution of vehicles in the various places and the travel performed by them. For example, in Manchester there were registered 12.6 percent of all of the vehicles in the State; and of the total travel on all highways and streets during the year, 14.8 percent was done by these vehicles. Rural areas contained 25.8 percent of all the vehicles in the State and performed 23.8 percent of the total travel by all vehicles in the State exclusive of travel by nonresidents.

A constitutional limitation places the levying of a tax on the privilege of selling gasoline outside of legislative power. It is possible, however, for the State to charge for the use of the public works it has built. Under this interpretation the State can levy a road toll. Since the amount of gasoline used is a measure of the use of the highways, the road toll is raised through a tax on gasoline. For all practical purposes this tax is like all other State gasoline taxes and is so considered in this survey.

TABLE 11.—*Mileage traveled, gasoline consumption, and gasoline-tax payments by passenger cars and by trucks and busses, distributed by place of ownership*

[Exclusive of nonresidents]

Place of ownership	Registrations	Total travel		Total gasoline consumption	Total gasoline tax paid		
		Vehicle-miles	Percent		Amount	Percent	Amount per vehicle
Rural areas:	*Number*			*Gallons*			
Passenger cars	21,811	144,800,000	[1] 22.8	9,865,000	$394,600	16.9	$18.09
Trucks and busses	5,100	39,100,000	[2] 28.2	3,685,000	147,400	6.3	28.90
Total	26,911	183,900,000	23.8	13,550,000	542,000	23.2	20.14
Places to 2,499:							
Passenger cars	19,140	140,400,000	[1] 22.1	9,685,000	387,400	16.5	20.24
Trucks and busses	3,852	27,100,000	[2] 19.6	2,625,000	105,000	4.5	27.26
Total	22,992	167,500,000	21.6	12,310,000	492,400	21.0	21.42
Places 2,500 to 14,999:							
Passenger cars	23,159	164,200,000	[1] 25.9	11,952,500	478,100	20.4	20.64
Trucks and busses	4,179	33,900,000	[2] 24.5	3,040,000	121,600	5.2	29.10
Total	27,338	198,100,000	25.6	14,992,500	599,700	25.6	21.94
Places 15,000 to 74,999:							
Passenger cars	11,849	91,100,000	[1] 14.3	7,047,500	281,900	12.0	23.79
Trucks and busses	2,134	18,700,000	[2] 13.5	1,907,500	76,300	3.3	35.75
Total	13,983	109,800,000	14.2	8,955,000	358,200	15.3	25.62
Manchester:							
Passenger cars	11,258	94,600,000	[1] 14.9	6,822,500	272,900	11.7	24.24
Trucks and busses	1,901	19,600,000	[2] 14.2	1,885,000	75,400	3.2	39.66
Total	13,159	114,200,000	14.8	8,707,500	348,300	14.9	26.47
State total:							
Passenger cars	87,217	635,100,000	82.1	45,372,500	1,814,900	77.5	20.81
Trucks and busses	17,166	138,400,000	17.9	13,142,500	525,700	22.5	30.62
Total	104,383	773,500,000	100.0	58,515,000	2,340,600	100.0	22.42

[1] Percentage of total for passenger cars.

[2] Percentage of total for trucks and busses.

The total (net after refunds) receipts from the gasoline tax were $2,638,800. The residents of New Hampshire paid $2,340,600 and nonresidents paid $298,200. The gasoline tax was second only to property taxes as a source of revenue, and was the largest item of the motor-vehicle receipts. The cost of administering the gasoline tax was only $3,600.

The 1932 gasoline tax rate was 4 cents per gallon, composed of a tax of 3 cents per gallon, the proceeds to be used for general highway expenditures on the State highway system, and a tax of 1 cent per gallon, the revenue to be used by the State exclusively for highway debt service. As was found for license fees, the larger the community the greater was the gasoline tax paid per vehicle.

The average gasoline tax paid by trucks and busses was $30.62 per vehicle, or nearly 50 percent greater than that paid by passenger cars. The average gasoline tax for all motor vehicles was $22.42 per vehicle.

Table 11 shows that, on the average, trucks and busses paid in gasoline taxes $9.81 more than passenger cars. The excess of the average license fee for trucks and busses over that for passenger cars was $11.97, making a total excess of $21.78. Since there were 17,166 trucks and busses licensed in the State, the amount of user revenues paid by trucks and busses was approximately $370,000 more than that paid by an equal number of passenger cars.

Trucks and busses contributed 17.9 percent of the travel and paid 22.5 percent of the gasoline taxes.

MISCELLANEOUS MOTOR-VEHICLE IMPOSTS

In lieu of the personal-property tax formerly charged against motor vehicles, a local permit fee has been substituted and is a prerequisite to registration. Motor-vehicle owners who pay the permit fee are exempt from the property tax. Those vehicles not reached by the permit fee, however, such as cars in the hands of dealers, are still charged with the personal-property tax.

The revenues from the fees go to the local communities in the same manner that general property revenues do, and the money is used for the general purposes of the town. Although received from motor-vehicle owners and consequently highway users, it is not specifically dedicated for highway purposes. In 1932, however, $91,000 or 17.7 percent of the $513,000 collected in permit fees was used for highway purposes. Permit fees paid by persons living in unorganized areas go into the county fund.

The average permit fee in urban communities was higher than in rural areas and the fee was highest in Manchester, the average there being $8.05 per vehicle. It is not surprising that the permit fee, being based on value and on the age of the vehicle, was higher in the urban communities than in the rural, since the newer, more valuable vehicles are owned in the places of greatest population.

Besides the registration fees, local permit fees, and gasoline taxes, there are a number of other imposts levied specifically on motor vehicles and their operators. Among these are drivers' and chauffeurs' licenses, transfer fees, manufacturers' and dealers' fees, and fines and penalties similar to those collected in other States. These are incidental fees of minor importance, collected in connection with the operation of the laws and regulations in the State. The total of these imposts in 1932 was $395,100, of which $356,500 was contributed by residents of New Hampshire.

TABLE 12.—*Average and total payments of motor-vehicle fees and gasoline taxes by owners of motor vehicles in 1932, distributed by place of ownership* [1]

Place of ownership	Payments per vehicle					Total payments					
	Registration fees	Gasoline tax	Miscellaneous imposts	Local permit fees	Total	Registration fees	Gasoline tax	Miscellaneous imposts	Local permit fees	Total	Percentage of total
Rural areas	$14.21	$20.14	$3.48	$4.21	$42.04	$382,500	$542,000	$93,700	$113,400	$1,131,600	23.7
Places to 2,499	14.83	21.42	3.42	4.64	44.34	341,700	492,400	78,700	106,700	1,019,500	21.3
Places 2,500 to 14,999	15.43	21.94	3.34	4.27	44.98	421,800	599,700	91,400	116,700	1,229,600	25.7
Places 15,000 to 74,999	15.75	25.62	3.41	5.03	49.81	220,300	358,200	47,700	70,300	696,500	14.6
Manchester	15.44	26.47	3.42	8.05	53.38	203,200	348,300	45,000	105,900	702,400	14.7
Total or average	15.04	22.42	3.42	4.91	45.79	1,569,500	2,340,600	356,500	513,000	4,779,600	100.0

[1] Excludes payments by nonresidents.

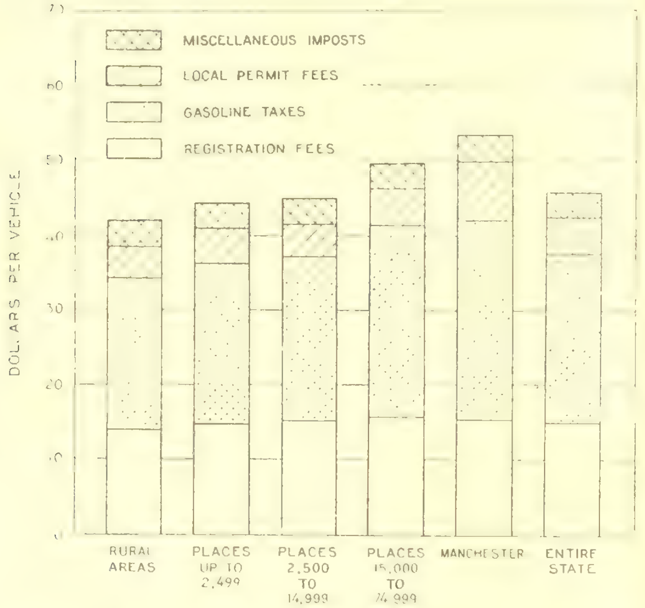

FIGURE 5.—AVERAGE MOTOR VEHICLE IMPOSTS AND GASOLINE TAXES PAID BY MOTOR VEHICLE OWNERS, DISTRIBUTED BY PLACE OF OWNERSHIP.

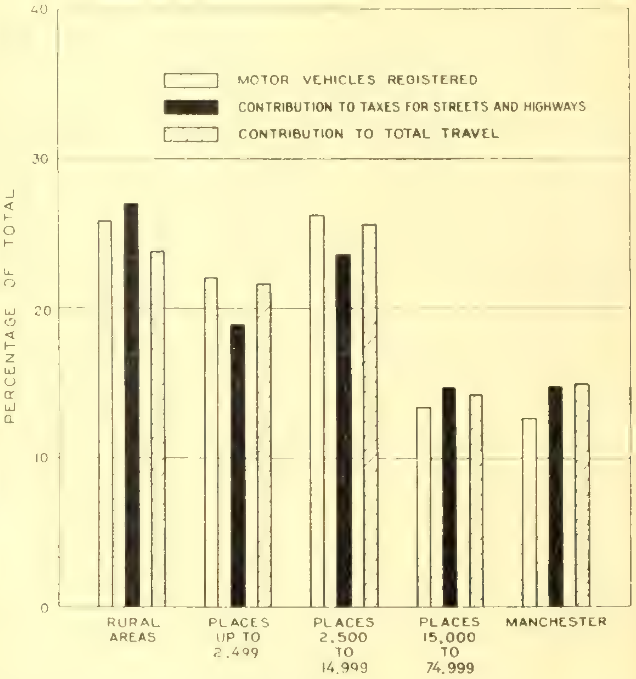

FIGURE 6.—PERCENTAGE DISTRIBUTION OF MOTOR VEHICLES REGISTERED, ALL MOTOR-VEHICLE IMPOSTS PAID, AND CONTRIBUTION TO TOTAL TRAVEL, DISTRIBUTED BY GOVERNMENTAL UNITS.

DATA ON MOTOR-VEHICLE TAXES AND TRAVEL SUMMARIZED

Table 12 summarizes the data on average registration fees and gasoline taxes paid in 1932. The total additional charges made against motor-vehicle owners are also shown. These data are presented graphically in figure 5.

Table 13 summarizes the relations between population, vehicles registered, registration fees and gasoline taxes paid, and travel performed, data that have been given in preceding paragraphs. Figure 6 shows the relations between registrations, contribution to highway taxes, and travel performed.

The following conclusions regarding motor vehicles, their taxation and travel, can be drawn:

1. The rural areas with 25.8 percent of the population contained 25.8 percent of the registered motor vehicles. Motor-vehicle owners in the rural areas paid 23.7 percent of the motor-vehicle imposts collected and contributed 23.8 percent of the total travel performed by New Hampshire vehicles.

2. The urban communities with 74.2 percent of the population contained 74.2 percent of the registered motor vehicles. Motor-vehicle owners in these urban areas paid 76.3 percent of the motor-vehicle imposts collected and contributed 76.2 percent of the total travel performed by residents.

3. The average registration fee paid was $15.04; the average gasoline tax was $22.42; the average miscellaneous motor-vehicle tax was $3.42; the average local permit fee was $4.91; and the total payment was $45.79 per vehicle in user revenues. Both registration fees and gasoline tax payments per vehicle were found to increase as the place of residence became more densely settled.

4. The average registration fee paid was $13.07 for passenger cars and $25.04 for trucks and busses. The average gasoline tax paid was $20.81 by passenger-car owners and $30.62 by owners of trucks and busses. The average payment per vehicle for registration fees and gasoline taxes was $33.88 for passenger cars, $55.66 for trucks and busses, and the average for all vehicles was $37.46.

5. Trucks and busses contributed 16.4 percent of the total registrations and 17.9 percent of the total travel by New Hampshire vehicles and paid 27.4 percent of the registration fees and 22.5 percent of the gasoline taxes.

TABLE 13.—*Comparison of the several classes of local governmental units as to population, motor vehicles registered, motor-vehicle taxes paid, and share of total travel performed by vehicles owned in these places*

Unit of government	Population	Motor vehicles registered	Registration fees paid	Gasoline taxes paid	Registration fees and gasoline taxes paid	All motor-vehicle imposts paid	Contribution to total travel
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Rural areas	25.8	25.8	24.4	23.2	23.7	23.7	23.8
Places to 2,499	17.3	22.0	21.8	21.0	21.3	21.3	21.6
Places 2,500 to 14,999	23.9	26.2	26.9	25.6	26.1	25.7	25.6
Places 15,000 to 74,999	16.5	13.4	14.0	15.3	14.8	14.6	14.2
Manchester	16.5	12.6	12.9	14.9	14.1	14.7	14.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

BONDED INDEBTEDNESS FOR HIGHWAYS ABOUT 40 PERCENT OF TOTAL

The total bonded indebtedness for all units of government in New Hampshire at the end of 1932 amounted to $26,131,000. Of this amount $10,242,000, or 39.2 percent, was incurred for highways and streets; $5,833,400, or 22.3 percent, was for education; $7,884,100, or 30.2 percent, was for public benefit; and $2,171,500, or 8.3 percent, was for governmental purposes. In New Hampshire as in other States, the extensive highway program was responsible for a large portion of the public debt. Table 14 shows the bonded indebtedness classified by purpose and by governmental unit.

The bonded indebtedness of the State government comprised $7,841,000, or 30 percent of the total. Of this amount, 67.6 percent, or $5,300,000, was for highway purposes. The entire State highway debt consisted of three series of bond issues—the New Hampshire flood bonds, the permanent improvement bonds, and the trunk-line completion bonds.

The New Hampshire flood bonds, authorized in 1927 for an amount not to exceed $3,000,000, were issued for the construction and reconstruction of the highways damaged or destroyed by floods in 1927.

A permanent highway bond issue was authorized in 1929 for the construction and reconstruction of trunk-line highways. The total issue was not to exceed $8,000,000.

The proceeds from the additional gasoline tax of 1 cent per gallon are used to service both of these issues.

Trunk-line completion bonds not to exceed $750,000 in amount were authorized in 1929 to provide "* * * for the assistance of cities and towns in the completion of the permanent improvement of existing trunk lines." It was in effect a loan to towns to enable them to defray their share of the cost of completing the gaps in the trunk-line highway system.

TABLE 14.—*Bonded indebtedness as of Dec. 31, 1932, classified by purpose of issue and by unit of government*

BY PURPOSE

	Amount	Percentage of total	Amount per capita
Highways and streets	$10,242,000	39.2	$22.01
Education	5,833,400	22.3	12.54
Public benefit	7,884,100	30.2	16.94
Government	2,171,500	8.3	4.67
Total	26,131,000	100.0	56.16

BY UNIT OF GOVERNMENT

	Amount	Percentage of total	Amount per capita
State	$7,841,000	30.0	$16.85
Counties	932,500	3.6	2.00
Rural areas	2,316,700	8.8	19.26
Urban communities	15,040,800	57.6	43.59
Total	26,131,000	100.0	56.16

NEW HAMPSHIRE EXPENDITURES IN 1932

The total expenditures for all purposes (exclusive of principal payments on bonds and loans) by all units of government in New Hampshire in 1932 were $28,298,000, of which $9,129,200 was expended for highways and streets, $7,624,500 for education, $9,867,000 for public benefit, and $1,677,300 for other governmental purposes.

Expenditures by the State were $10,242,200; by the counties, $2,166,300; by incorporated places, $11,229,600; and by rural areas, $4,659,900.

Of the total expenditures, 40.3 percent was made in rural areas; 13.2 percent in incorporated places to 2,499 population; 19.1 percent in places with 2,500 to 14,999 population; 14.7 percent in places with 15,000 to 74,999 population; and 12.7 percent in Manchester.

The State also issued bonds in the amount of $1,541,000 for public benefit purposes and $1,000,000 for other governmental purposes. There was no State bonded debt for education.

The county indebtedness amounted to only $932,500, all of which was incurred for public benefit.

The urban communities had a total indebtedness of $15,040,800, or 57.6 percent of the total. Over 27 percent of this was incurred for highways and streets.

Of the total indebtedness of $2,316,700 incurred by the rural areas, 36.2 percent, or $839,400, was for highway purposes.

The per-capita debt ranged from $19.26 in the rural areas to $54.84 in the city of Manchester. The per-capita debt contracted by the counties was $2; by the State, $16.85.

Debt service consists of interest and principal payments on indebtedness. The total debt-service payments in 1932 were $5,464,400, of which $1,638,600, or 30 percent, was for highways. Contrary to the usual situation, in New Hampshire the percentage of debt service for each of the purposes differed considerably from the percentage of outstanding indebtedness for the same purpose.

For the entire State nearly four-fifths of the debt service consisted of principal payments, and the balance was interest. State payments, however, showed a higher proportion of principal payments, amounting to almost 88 percent of the total debt service on State debts. Table 15 shows these figures for Manchester and for the rest of the State.

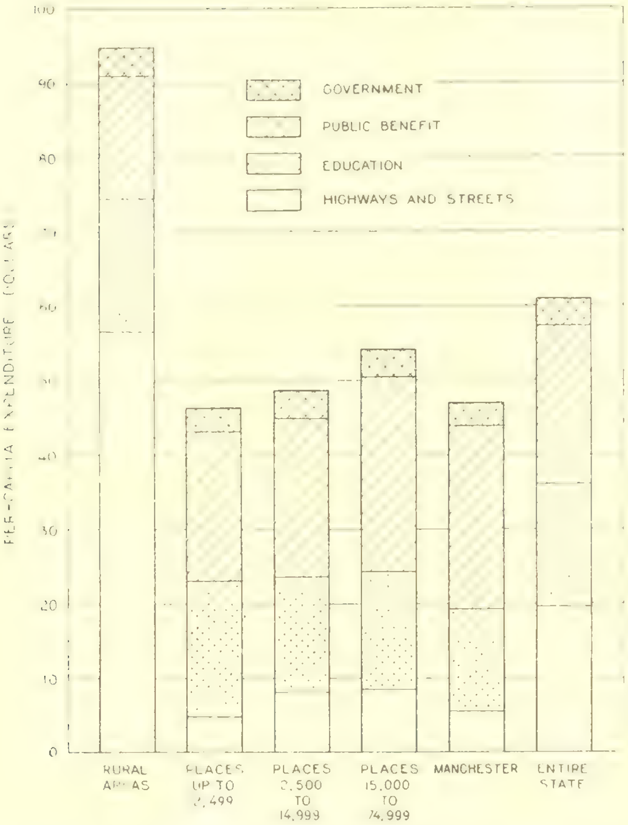

Figure 7.—Per-Capita Expenditures for Different Purposes, Distributed by Governmental Units Where Expenditures Were Made.

Table 15.—*Payments for debt service in 1932*

Unit of government	Principal	Interest	Total
State:			
Total amount	$2,115,000	$296,900	$2,411,900
Per-capita amount	4.54	0.64	5.18
Manchester:			
Total amount	739,700	288,000	1,027,700
Per-capita amount	9.63	3.75	13.38
Balance of State:			
Total amount	1,476,400	548,400	2,024,800
Per-capita amount	3.80	1.41	5.21
All governmental units:			
Total amount	4,331,100	1,133,300	5,464,400
Per-capita amount	9.31	2.43	11.74

HIGHWAY EXPENDITURES NEARLY $20 PER CAPITA

The total expenditure by all units of government for all purposes in 1932 was $28,298,000, equal to $60.82 per capita. Table 16 shows that the largest amount per capita, $21.21, was for public benefit. The amount spent for this purpose was $9,867,000, or 34.9 percent of the total. For highways and streets, 32.3 percent, or $9,129,200, was spent; for education, 26.9 percent, or $7,624,500; and for government, 5.9 percent, or $1,677,300. The total amount includes $1,133,300 of interest payments on funded debt.

The State spent $10,242,000, or 36.2 percent, of the total expenditures. Of this amount 57.6 percent, or $5,895,100, was spent for highways and streets; 27.9 percent, or $2,855,500, for public benefit; 12.3 percent, or $1,263,900, for education; and 2.2 percent, or $227,700, for government.

The $4,331,100 of principal payments is excluded, as it represents repayments of funds charged as expenditures in previous years.

Table 16.—*Classification of the total expenditures in 1932 by the State, the counties, and the local units of government, and per-capita expenditures by purpose*

Expended by—	Total expenditure		Per-capita expenditures for—				
	Amount	Percent	Highways and streets	Education	Public benefit	Government	Total
State	$10,242,200	36.2	$12.67	$2.72	$6.13	$0.49	$22.01
Counties	2,166,300	7.6			4.41	.25	4.66
Rural areas	4,659,900	16.5	14.12	15.18	6.43	3.02	38.75
Places to 2,499	2,336,200	8.3	1.41	15.54	9.50	2.60	29.05
Places 2,500 to 14,999	3,601,400	12.7	5.00	12.84	11.49	3.10	32.43
Places 15,000 to 74,999	2,854,700	10.1	6.58	13.17	14.42	3.04	37.21
Manchester	2,437,300	8.6	4.70	11.06	13.54	2.42	31.72
Total	28,298,000	100.0	19.62	16.39	21.21	3.60	60.82

Table 17.—*Comparison of expenditures by governmental units for various purposes*

DISTRIBUTION BY PURPOSE

Expended by—	Highways and streets	Education	Public benefit	Government	All purposes
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
State	57.6	12.3	27.9	2.2	100.0
Counties			94.7	5.3	100.0
Rural areas	36.4	39.2	16.6	7.8	100.0
Places to 2,499	4.8	53.5	32.7	9.0	100.0
Places 2,500 to 14,999	15.4	39.6	35.4	9.6	100.0
Places 15,000 to 74,999	17.7	35.4	38.7	8.2	100.0
Manchester	14.8	34.9	42.7	7.6	100.0
Total	32.3	26.9	34.9	5.9	100.0

DISTRIBUTION BY GOVERNMENTAL UNIT

Expended by—	Highways and streets	Education	Public benefit	Government	All purposes
State	64.6	16.6	28.9	13.6	36.2
Counties			20.8	6.8	7.6
Rural areas	18.6	23.9	7.8	21.6	16.5
Places to 2,499	1.2	16.4	7.8	12.5	8.3
Places 2,500 to 14,999	6.1	18.7	12.9	20.5	12.7
Places 15,000 to 74,999	5.5	13.3	11.2	13.9	10.1
Manchester	4.0	11.1	10.6	11.1	8.6
Total	100.0	100.0	100.0	100.0	100.0

The counties, which are of relative unimportance from the standpoint of total expenditures, expended only $2,166,300, nearly all of which was for public benefit. No expenditures were made by the counties for education or for highways and streets.

The rural areas spent $4,659,900, or approximately 16.5 percent of all expenditures made in the State. Almost 40 percent of this amount was expended for educational purposes and more than 36 percent was for highways.

A large amount of the $11,229,600 expended by the urban areas was for public benefit. The per-capita expenditures for this purpose ranged from $9.50 to $14.42. The per-capita expenditure for highways and streets in the urban places was much less than in the rural areas. Expenditures for government were fairly uniform throughout all localities.

Table 17 shows data on expenditures made by each unit of government for the various purposes. The top half of this table divides the expenditures made by each governmental agency according to the purpose for which it was made. The bottom half of the table divides the expenditures for each purpose according to the amount expended by each unit of government.

To allocate the expenditures as finally made in the rural and urban areas, it was necessary to distribute the State and county expenditures as made for the residents in these territories.

Table 18 and figure 7 show these data on a per-capita basis. It is apparent that the total per-capita cost of the activities carried on by and in governmental units was less in urban than in rural areas. This is contrary to the condition usually found in other States. The metropolitan areas with their expensive public services necessary to the welfare of large numbers of people living in a small territory usually have a higher per-capita public cost than in places where the public demands are less intense. In general this was also true of New Hampshire, but the total was affected by the heavy State highway expenditures in the rural areas. Although these funds were expended outside of urban places, they were a benefit to the entire traveling public of the State and should not be construed as a subsidy to the place where spent.

HIGHWAY AND STREET EXPENDITURES ANALYZED

In 1932, $9,129,200 was expended upon all highways and streets in New Hampshire. Of this, $6,798,300, or 74.5 percent, was spent in rural areas and $2,330,900, or 25.5 percent, in urban areas. These were the actual current expenditures for 1932, including interest upon indebtedness, but not payment of principal on the highway debt. It is particularly important to exclude the payment of principal on debt, otherwise a duplication of cost items results. It is also necessary to avoid duplication of expenditures caused by the transfer of funds from one governmental unit to another. The highway and other cost figures in this report are the actual current costs with all duplications eliminated.

RELATIONS BETWEEN HIGHWAY TAXES PAID, HIGHWAY EXPENDITURES, AND TRAVEL

There were 11,750 miles of rural highways in New Hampshire in 1932. The State highway system consisted of 3,033 miles, divided into 1,596 miles of State highways and 1,437 miles of State-aid roads. There were 8,717 miles of local roads and 561 miles of urban streets.

The total travel (exclusive of that performed by vehicles owned by nonresidents) on all highways and streets in New Hampshire during the year 1932 was approximately 774 million vehicle-miles, of which 23.8 percent was performed by vehicles of rural ownership; 21.6 percent by vehicles owned in incorporated places having a population to 2,499; 25.6 percent by vehicles owned in places of 2,500 to 14,999 population; 14.2 percent by vehicles owned in places of 15,000 to 74,999 population; and 14.8 percent by vehicles owned in Manchester.

Expenditures on State highways in 1932 were $3,461,100; on the State-aid system, $2,723,200; on the local town roads, $1,409,500; and on urban streets, $1,535,400.

Of the total property taxes expended on all roads and streets, 11.5 percent was expended on State and State-aid highways, 38.8 percent on the local town roads, and 49.7 percent on urban streets.

Of the total motor-vehicle taxes, including nonresident fees, expended on all highways and streets, 40.9 percent was expended on State highways; 55.2 percent on State-aid roads; 3.9 percent on the local town roads; and none on urban streets.

Of the total of all taxes and imposts expended on all roads and streets, rural property and motor-vehicle owners paid 32 percent, and travel by rural vehicles made up 23.8 percent of the total travel on all roads and streets; property and motor-vehicle owners in urban areas paid 61.8 percent, and travel by urban vehicles made up 76.2 percent of the total travel. Out-of-State residents contributed 6.2 percent of the imposts. The amount of travel they performed is unknown.

On the class 1 roads, $3,278,500 was expended in 1932. This was exclusive of interest payments on funded debt. Of this amount $1,692,600 was spent for construction, $1,396,000 for maintenance, and $189,900 for departmental overhead. Of the total, $2,827,300, or 86.2 percent, was expended in rural areas.

New Hampshire follows the policy of paying for the cost of its trunk highways out of user revenues and for this purpose derives funds primarily from gasoline taxes and license fees. In addition, $1,000,000 from bond sales and $371,400 of Federal-aid funds were available for the 1932 program. After paying the cost of administration, the proceeds from the 3-cent gasoline tax and the license fees are for use by the State highway department. The net sum so designated was $3,755,300, of which $1,493,300, or almost 40 percent, was used upon the State trunk-line highway system.

Upon the class 2 or State-aid roads, $2,723,200 was expended, of which $1,605,100 was for construction, $998,000 for maintenance, and $120,100 for overhead. Of the $1,605,100 spent for construction, $937,800 was for the emergency construction program.

The interest charges incidental to the State road systems were $182,600. The total cost of the State road systems, therefore, amounted to $6,184,300. Table 19 shows the construction and maintenance expenditures on the system.

The local communities expended a total of $3,234,100 upon all highway and street programs, and of this amount $2,944,900 was expended locally upon the town roads and streets. Of this total, $146,600 went for construction, $2,290,600 for maintenance, and $507,700 for general overhead. This is not the complete overhead charge, as the amounts paid to the local road agencies could not be segregated.

TABLE 18.—*Comparison of per-capita expenditures by purpose and by classes of local units where the expenditures were made*

Expended in—	Highways and streets	Education	Public benefit	Government	Total
Rural areas	$56.53	$17.91	$16.68	$3.75	$94.87
Places to 2,499	4.72	18.25	20.00	3.35	46.32
Places 2,500 to 14,999	8.02	15.52	21.33	3.85	48.72
Places 15,000 to 74,999	8.37	15.92	26.04	3.80	54.13
Manchester	5.46	13.78	24.54	3.08	46.86
Average for State	19.62	16.39	21.21	3.60	60.82

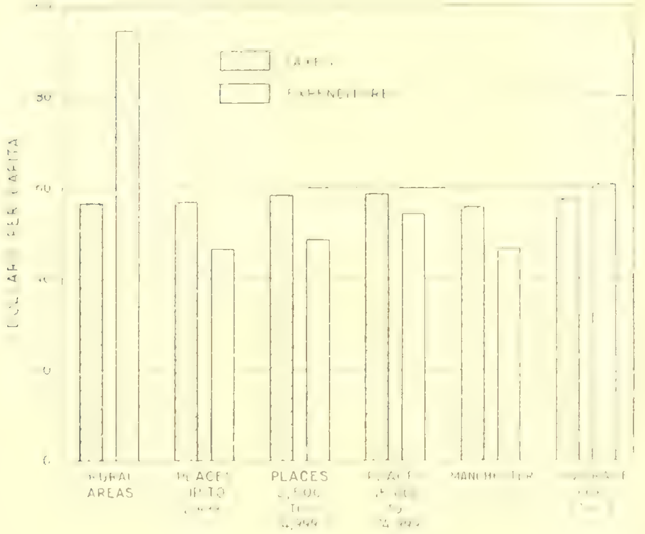

Figure 8.—Per-Capita Taxes and Expenditures in the Several Classes of Local Units and in the State as a Whole.

Table 19.—*Expenditures for construction and maintenance on the State highway system in 1932*

Highway system	Construction		Maintenance		Total		Percentage of total construction and maintenance
	Amount	Percent	Amount	Percent	Amount	Percent	
State (class 1)	$1,692,600	54.8	$1,396,000	45.2	$3,088,600	100.0	54.3
State aid (class 2)	1,605,100	61.7	998,000	38.3	2,603,100	100.0	45.7
Total	3,297,700	57.9	2,394,000	42.1	5,691,700	100.0	100.0

Except for a small amount of State aid to some of the rural communities, the local roads were financed entirely from local revenues. Even the class 4 roads on the State numbered system in cities were financed by the places through which they pass. New Hampshire does not have a special property tax for highways. All of the public receipts are placed in the common fund from which expenditures for all purposes are made. Therefore, local highway costs are met by a tax on property only in the proportion that the property tax bears to the total local receipts.

The combined expenditures by the State and local governments for roads in rural areas amounted to $6,798,300; for highways and streets in urban communities, $2,330,900. A comparison of these expenditures with the taxes imposed in the various areas for highway and street purposes is shown in table 20. The figures on the ratio of expenditures to taxes do not accurately portray the current highway picture, because a substantial portion of the taxes levied in 1932 was not expended for the 1932 highway program.

There was a flow of revenue from the urban to the rural areas. It is not to be inferred that such transfer of funds is unwarranted, nor that an undue benefit is necessarily conferred upon the community where spent. The highway funds are used for constructing rural roads that serve all of the people in the State. If the roads so built serve the transportation needs of residents of urban communities, then logically the funds should be derived in due proportion from all of the communities benefited.

Table 20.—*Comparison of highway and street expenditures and taxes in the several classes of local units in 1932*

Class of local unit	Highway and street expenditures		Highway and street taxes		Ratio of expenditures to taxes
	Amount	Percent	Amount	Percent	
Rural areas	$6,798,300	74.5	$2,150,000	27.9	1:0.3
Places to 2,499	379,200	4.1	1,459,800	18.9	1:3.9
Places 2,500 to 14,999	890,500	9.8	1,826,500	23.7	1:2.1
Places 15,000 to 74,999	641,600	7.0	1,162,200	15.1	1:1.8
Manchester	419,600	4.6	1,113,400	14.4	1:2.7
Total	9,129,200	100.0	7,711,900	100.0	1:0.8

TOTAL EXPENDITURES EXCEED TAXATION BY $3.65 PER CAPITA

Table 21 and figure 8 indicate that there is a flow of funds to the less populous areas. The per-capita expenditures in the rural areas exceeded the per-capita taxation by $38.57. The expenditures in the urban areas, on the other hand, were less than taxes.

The amount of imposts received and expenditures made do not balance, primarily because of the effect of financing current costs from borrowings, balances, and reserves. Taxes, therefore, always lag behind expenditures.

Tables 22, 23, and 24 give rather comprehensive figures that make possible many comparisons concerning the flow of funds between urban and rural communities. For example, referring to tables 22 and 23, $11,409,500 was expended in the rural areas by all governmental agencies, while the rural areas paid $6,769,900 in taxes. The per-capita expenditure in rural areas was $94.87, while the per-capita tax paid was $56.30. Of the total expenditure in rural areas, 40.8 percent was made by the local town governments, and 59.2 percent in or for the towns by the State and counties, primarily for highway purposes. This indicates a large flow of funds for highway purposes from the urban communities to the rural communities, the State and county spending $5,099,600, in the rural areas while these same areas contributed but $1,018,200.

Table 25 shows the relations between governmental units and population, motor-vehicle ownership, property valuation, taxes paid, and expenditures made in 1932.

Table 21.—*Comparison of per-capita property valuation, taxation, and expenditures in 1932, in the various classes of local units and in the entire State*

Unit of government	Per-capita property valuation	Per-capita taxation	Per-capita expenditures	Ratio of expenditures to taxation
Rural	$1,524	$56.30	$94.87	1:0.6
Places to 2,499	1,185	56.69	46.32	1:1.2
Places 2,500 to 14,999	1,250	58.16	48.72	1:1.2
Places 15,000 to 74,999	1,301	58.79	54.13	1:1.1
Manchester	1,382	55.98	46.86	1:1.2
Average for State	1,340	57.17	60.82	1:0.9

SOURCES OF FUNDS SPENT ON HIGHWAYS AND STREETS ANALYZED

The sources of revenue for expenditure on the various highway and street systems, classified both by agency providing the funds and by type of fund, are shown in table 26. Of the $9,129,200 spent on all highways and streets in the State, 4.1 percent, or $371,400, was provided by Federal aid, all of which was expended on the State highways. The State provided 62.2 percent of

TABLE 22.—*Classification of all taxes as levied against and paid by residents of rural and urban areas*

Area and type of impost	Tax-levying agency								
	Local governments			State and county governments			All governments		
	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita
Rural areas:									
Property	$3,557,400	85.6	$29.58	$723,000	27.6	$6.01	$4,280,400	63.2	$35.59
Other	596,100	14.4	4.96	1,893,400	72.4	15.74	2,489,500	36.8	20.70
Total	4,153,500	100.0	34.54	2,616,400	100.0	21.75	6,769,900	100.0	56.29
Urban areas:									
Property	10,288,400	82.7	29.82	1,774,100	24.0	5.14	12,062,500	60.8	34.96
Other	2,145,000	17.3	6.22	5,621,800	76.0	16.29	7,766,800	39.2	22.51
Total	12,433,400	100.0	36.04	7,395,900	100.0	21.43	19,829,300	100.0	57.47
Entire State:									
Property	13,845,800	83.5	29.76	2,497,100	24.9	5.37	16,342,900	61.4	35.13
Other	2,741,100	16.5	5.89	7,515,200	75.1	16.15	10,256,300	38.6	22.04
Total	16,586,900	100.0	35.65	10,012,300	100.0	21.52	26,599,200	100.0	57.17

TABLE 23.—*Classification of total expenditures by purpose as made by all units of government*

Area and purpose	Unit of government								
	Local governments			State and county governments			All governments		
	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita
Rural areas:									
Highways and streets	$1,698,700	36.4	$14.12	$5,099,600	75.5	$42.41	$6,798,300	59.6	$56.53
Education	1,825,000	39.2	15.18	328,300	4.9	2.73	2,153,300	18.9	17.91
Public benefit	773,100	16.6	6.43	1,233,200	18.3	10.25	2,006,300	17.6	16.68
Government	363,100	7.8	3.02	88,500	1.3	.73	451,600	3.9	3.75
Total	4,659,900	100.0	38.75	6,749,600	100.0	56.12	11,409,500	100.0	94.87
Urban areas:									
Highways and streets	1,535,400	13.7	4.45	795,500	14.1	2.31	2,330,900	13.8	6.76
Education	4,535,600	40.4	13.15	935,600	16.5	2.71	5,471,200	32.4	15.86
Public benefit	4,186,300	37.3	12.13	3,674,400	64.9	10.65	7,860,700	46.5	22.78
Government	972,300	8.6	2.82	253,400	4.5	.73	1,225,700	7.3	3.55
Total	11,229,600	100.0	32.55	5,658,900	100.0	16.40	16,888,500	100.0	48.95
Entire State:									
Highways and streets	3,234,100	20.4	6.95	5,895,100	47.5	12.67	9,129,200	32.3	19.62
Education	6,360,600	40.0	13.67	1,263,900	10.2	2.72	7,624,500	26.9	16.39
Public benefit	4,959,400	31.2	10.66	4,907,600	39.5	10.55	9,867,000	34.9	21.21
Government	1,335,400	8.4	2.87	341,900	2.8	.73	1,677,300	5.9	3.60
Total	15,889,500	100.0	34.15	12,408,500	100.0	26.67	28,298,000	100.0	60.82

TABLE 24.—*Classification of taxes used for highway and street purposes as levied against and paid by residents of rural and urban areas*

Area and type of impost	Tax levying agency								
	Local governments			State and county governments			All governments		
	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita	Amount	Percent	Amount per capita
Rural areas:									
Property	$978,400	86.4	$8.14				$978,400	45.5	$8.14
Other	153,100	13.6	1.27	$1,018,200	100.0	$8.47	1,171,600	54.5	9.74
Total	1,131,800	100.0	9.41	1,018,200	100.0	8.47	2,150,000	100.0	17.88
Urban areas:									
Property	1,887,400	81.6	5.47				1,887,400	33.9	5.47
Other	426,100	18.4	1.24	3,248,400	100.0	9.41	3,674,500	66.1	10.65
Total	2,313,500	100.0	6.71	3,248,400	100.0	9.41	5,561,900	100.0	16.12
Entire State:									
Property	2,865,800	83.2	6.16				2,865,800	37.2	6.16
Other	579,500	16.8	1.24	4,266,600	100.0	9.17	4,846,100	62.8	10.41
Total	3,445,300	100.0	7.40	4,266,600	100.0	9.17	7,711,900	100.0	16.57

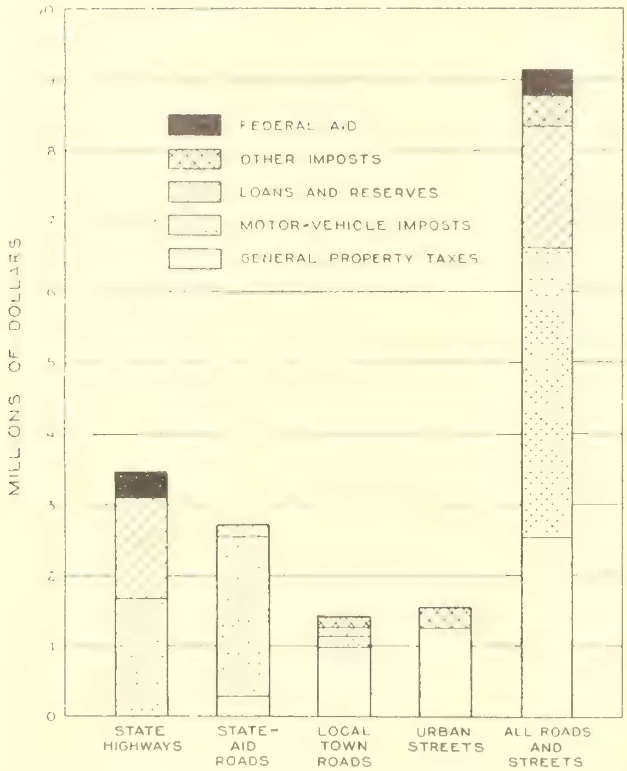

Figure 9.—Distribution of Total Expenditures for Highways and Streets, Showing Sources of Funds.

Table 25.—*Distribution of population, motor-vehicle ownership, property valuation, taxes paid, and expenditures made in the several classes of local governmental units in 1932*

Unit of government	Population	Motor-vehicle ownership	Property valuation	Taxes paid	Expenditures made
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Rural areas	25.8	25.8	29.4	25.4	40.3
Places to 2,499	17.3	22.0	15.3	17.1	13.2
Places 2,500 to 14,999	23.9	26.2	22.3	24.3	19.1
Places 15,000 to 74,999	16.5	13.4	16.0	17.0	14.7
Manchester	16.5	12.6	17.0	16.2	12.7
Total	100.0	100.0	100.0	100.0	100.0

the money expended on highways and streets. The remainder, $3,072,900, was furnished by the local governments.

Only $1,535,400 of current taxes was expended by the urban areas for the highway program in 1932, although the total taxes levied in 1932 for highway purposes by these communities amounted to $2,313,500. The reasons for the difference between the taxes levied and the expenditures made for the current highway program were:

1. Additional levies were needed to meet the principal payments due on more than $3,500,000 of municipal highway indebtedness. These payments are not included in the definition of expenditures used in these studies.
2. Taxes for streets in the municipalities included levies for purposes that are not included in our definition of highways, such as street lighting and street cleaning.
3. Tax delinquency caused a difference between the amount levied and the amount collected.

Table 26.—*Funds expended on highways and streets in 1932, and the approximate amounts and percentages of these funds provided by imposts made by the various governmental units, and by loan and reserve funds*

Highway system and form of revenue	Governmental agency providing funds: Federal Government	State	Local governments	Total	Percentage of total current tax funds	Percentage of total funds
State road system:						
State highways:					*Pct.*	*Pct.*
Loans or reserves		$1,402,000		$1,402,000		
Current taxes	$371,400	$1,675,900	$11,800	$2,059,100	27.7	
Total	$371,400	$3,077,900	$11,800	$3,461,100		37.9
Percentage distribution	10.7	88.9	0.4	100.0		
State-aid roads:						
Loans or reserves		$183,800		$183,800		
Current taxes		$2,262,000	$277,400	$2,539,400	34.2	
Total		$2,445,800	$277,400	$2,723,200		29.8
Percentage distribution		89.8	10.2	100.0		
Entire State system:						
Loans or reserves		$1,585,800		$1,585,800		
Current taxes	$371,400	$3,937,900	$289,200	$4,598,500	61.9	
Total	$371,400	$5,523,700	$289,200	$6,184,300		67.7
Percentage distribution	6.0	89.3	4.7	100.0		
Local rural roads:						
Loans or reserves			$116,500	$116,500		
Current taxes		$161,200	$1,131,800	$1,293,000	17.4	
Total		$161,200	$1,248,300	$1,409,500		15.5
Percentage distribution		11.4	88.6	100.0		
Urban streets:						
Loans or reserves						
Current taxes			[1] $1,535,400	$1,535,400	20.7	
Total			$1,535,400	$1,535,400		16.8
Percentage distribution			100.0	100.0		
All highways and streets:						
Loans or reserves		$1,585,800	$116,500	$1,702,300		
Current taxes	$371,400	$4,099,100	$2,956,400	$7,426,900	100.0	
Total	$371,400	$5,684,900	$3,072,900	$9,129,200		100.0
Percentage distribution	4.1	62.2	33.7	100.0		

[1] Total taxes levied for highways, $2,313,500; only $1,535,400 needed for current highway program.

Table 27 and figure 9 show the sources of revenue expended for highways and streets by type of impost and the amounts contributed for each of the systems by the residents of the rural and urban areas. The imposts on motor-vehicle owners include only license fees, gasoline taxes, and miscellaneous motor-vehicle imposts. It was impossible to segregate the proceeds from the permit fees used for highways. This amount, $91,000, is included in the other imposts used for local roads and streets.

Table 28 is a summary of the taxes and expenditures in New Hampshire in 1932 based on data presented previously in this report. The $1,000 unit is not identical for taxes and expenditures. To balance the tabulation exactly it would be necessary to include the proceeds from bonds and loans under taxes and principal payments under expenditures. The complete figures for such a presentation are not available. The table gives a helpful picture, however, of the relations between money received from imposts and the actual expenditures for the various purposes.

SUMMARY

1. Only 4.7 percent of the funds expended on State and State-aid roads was raised from taxes on property.
2. Rural property owners paid no tax for urban streets.

TABLE 27.—*Amounts of the 1932 taxes and imposts expended on the current highway program,[1] listed according to highway system, type of tax, and class of local unit in which the tax was paid*

Paid by taxpayers in—	Highway system										Percentage of total
	State roads		State-aid roads		Local town roads		Urban streets		All highways and streets		
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	
IMPOSTS ON GENERAL PROPERTY											
Rural areas	$10,100	0.8	$233,500	19.1	$978,400	80.1			$1,222,000	100.0	48.5
Places to 2,499			300	.3			$93,000	99.7	93,300	100.0	3.7
Places 2,500 to 14,999	1,700	.4	18,600	4.0			443,100	95.6	463,400	100.0	18.4
Places 15,000 to 74,999			25,000	5.6			423,200	94.4	448,200	100.0	17.8
Manchester							293,500	100.0	293,500	100.0	11.6
Total	11,800	.5	277,400	11.0	978,400	38.8	1,252,800	49.7	2,520,400	100.0	100.0
IMPOSTS ON MOTOR VEHICLES											
Rural areas	358,200	40.7	483,400	54.9	39,300	4.4			880,900	100.0	21.5
Places to 2,499	319,000	40.6	430,500	54.9	35,100	4.5			784,600	100.0	19.2
Places 2,500 to 14,999	386,700	40.6	521,900	54.8	43,400	4.6			952,000	100.0	23.2
Places 15,000 to 74,999	218,800	40.8	295,300	55.0	22,600	4.2			536,700	100.0	13.1
Manchester	207,700	40.8	280,400	55.1	20,800	4.1			508,900	100.0	12.4
Nonresident fees	185,500	42.5	250,500	57.5					436,000	100.0	10.6
Total	1,675,900	40.9	2,262,000	55.2	161,200	3.9			4,099,100	100.0	100.0
OTHER IMPOSTS											
Rural areas					153,400	100.0			$153,400	100.0	35.2
Places to 2,499							20,100	100.0	20,100	100.0	4.6
Places 2,500 to 14,999							112,800	100.0	112,800	100.0	25.9
Places 15,000 to 74,999							81,800	100.0	81,800	100.0	18.7
Manchester							67,900	100.0	67,900	100.0	15.6
Total					153,400	35.2	282,600	64.8	436,000	100.0	100.0
ALL IMPOSTS											
Rural areas	368,300	16.3	716,900	31.8	1,171,100	51.9			2,256,300	100.0	32.0
Places to 2,499	319,000	35.5	430,800	48.0	35,100	3.9	113,100	12.6	898,000	100.0	12.7
Places 2,500 to 14,999	388,400	25.4	540,500	35.4	43,400	2.8	555,900	36.4	1,528,200	100.0	21.7
Places 15,000 to 74,999	218,800	20.5	320,300	30.0	22,600	2.1	505,000	47.4	1,066,700	100.0	15.1
Manchester	207,700	23.9	280,400	32.2	20,800	2.4	361,400	41.5	870,300	100.0	12.3
Nonresident fees	185,500	42.5	250,500	57.5					436,000	100.0	6.2
Total	1,687,700	23.9	2,539,400	36.0	1,293,000	18.3	1,535,400	21.8	7,055,500	100.0	100.0
OTHER FUNDS											
Federal aid	371,400	100.0							371,400	100.0	
Loans and reserves	1,402,000	82.4	183,800	10.8	116,500	6.8			1,702,300	100.0	
Grand total	3,461,100	37.9	2,723,200	29.8	1,409,500	15.5	1,535,400	16.8	9,129,200	100.0	

[1] Does not include costs of administering motor-vehicle taxes and principal payments on highway debts.

3. Of the total tax on rural property expended for highway purposes—

(*a*) 19.9 percent was expended on State and State-aid roads.

(*b*) 80.1 percent was expended on local rural roads.

4. Of the total tax on urban property expended for highway and street purposes—

(*a*) 3.5 percent was expended on State and State-aid roads.

(*b*) 96.5 percent was expended on urban streets.

5. Since, of the total assessed property valuation of $623,381,700, 29.4 percent, or $183,277,500, was in rural areas, and 70.6 percent, or $440,104,200, was in urban areas—

(*a*) Expenditures from property taxes for all highways and streets were at the following rates per $100 of assessed valuation:

Rural—66.7 cents.
Urban—29.5 cents.

(*b*) Expenditures from property taxes for State and State-aid roads were at the following rates per $100 of assessed valuation:

Rural—13.3 cents.
Urban—1 cent.

(*c*) Expenditures from property taxes for local town roads were at the following rates per $100 of assessed valuation:

Rural—53.4 cents.
Urban—No tax.

(*d*) Expenditures from property taxes for urban streets were at the following rates per $100 of assessed valuation:

Rural—No tax.
Urban—28.5 cents.

(Continued on p. 40)

DIMENSIONS OF TESTING EQUIPMENT AFFECT HUBBARD-FIELD STABILITY VALUES

Reported by J. T. PAULS, Senior Highway Engineer, Division of Tests, Bureau of Public Roads[1]

STABILITY of bituminous mixtures against shoving or rutting is recognized as an important requirement for satisfactory road behavior. Laboratory tests to determine this quality of a bituminous mixture are therefore of particular value in connection with the design and study of bituminous surfaces.

Several types of stability test are now in use, one of which is the Hubbard-Field test. This test has been used extensively in the Bureau's laboratory test work and has, in general, given very satisfactory results in testing fine-aggregate mixtures. Although the test has been adapted to the testing of coarse-aggregate mixtures by substituting larger molding and testing equipment, it has not been so used by the Bureau. This study of the effect of variation in the dimensions of molding and testing equipment is therefore concerned only with the equipment used in testing fine-aggregate mixtures. A working drawing of the equipment, showing standard dimensions, is shown in figure 1.[2]

In performing the Hubbard-Field stability test a prepared cylinder of the mixture 2 inches in diameter and 1 inch high is forced through a 1¾-inch circular opening at a fixed rate of speed. The load in pounds required to do this is designated as the stability of the mixture.

In some recent cooperative work, marked discrepancies were found between the stabilities obtained on certain mixtures by the Bureau and those obtained on the same mixtures by the cooperating agency. Investigation disclosed that the equipment in use in both laboratories was worn and that the discrepancies were caused by slight differences in the dimensions of the forming and testing molds and the testing rings. Since no tolerances have ever been established for this testing equipment, it was decided to make a study of the effect of slight variations in these dimensions. For this purpose, three sets of equipment were made: One set had standard dimensions; one set was slightly undersize; and one set was slightly oversize. The sizes selected are given in table 1.

Table 1.—*Dimensions of the three sets of equipment studied*

Equipment	Internal diameter			External diameter of bottom plate of plunger
	Forming mold	Testing mold	Testing ring	
	Inches	*Inches*	*Inches*	*Inches*
Undersize	1.98	2.00	1.74	1.978
Standard	2.00	2.02	1.75	1.998
Oversize	2.02	2.04	1.76	2.018

All of the forming molds now in use by the Bureau are made of a specially hardened steel and the testing mold has a hardened steel lining to reduce wear. Figure 2 shows details of this testing mold.

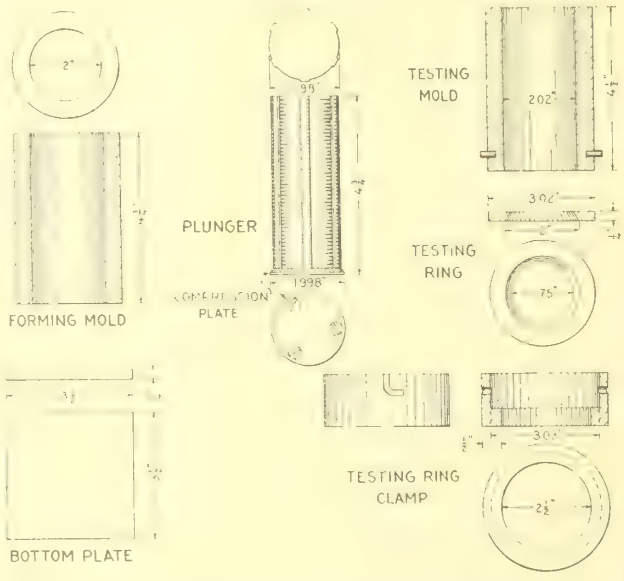

Figure 1.—Details of Forming and Testing Molds, Plunger, Testing Ring, and Ring Clamp.

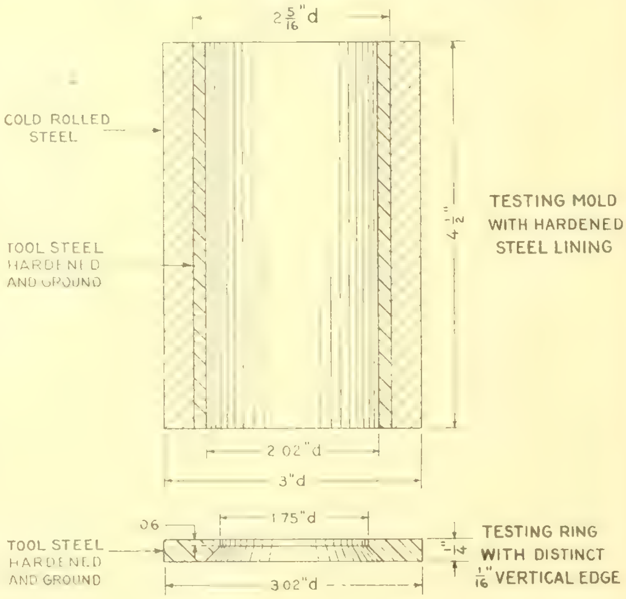
2 5/16"d
COLD ROLLED STEEL
TOOL STEEL HARDENED AND GROUND
4½"
TESTING MOLD WITH HARDENED STEEL LINING
2.02"d
3"d
.06
1.75"d
TOOL STEEL HARDENED AND GROUND
½"
3.02"d
TESTING RING WITH DISTINCT 1/16" VERTICAL EDGE

Figure 2.—Suggested Design of Testing Mold and Ring to Reduce Wear.

A modification in the design of the testing ring has recently been recommended by Mr. Hubbard in order to reduce wear. Rings of the new type, the details of which are shown in figure 2, were used in this study. Previous investigations by Mr. Hubbard have indicated that this change in design does not affect the test results.

The investigation was confined to a study of the effect of variations in the dimensions of the forming

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[1] [illegible] at the meeting of the Association of Asphalt Paving Technologists held in Cleveland, Ohio.

[2] See A Practical Method for Determining the Relative Stability of Fine-Aggregate [illegible] Paving Mixtures, by Prevost Hubbard and F. C. Field. Proceedings A. S. T. M., vol. 25, pt. II.

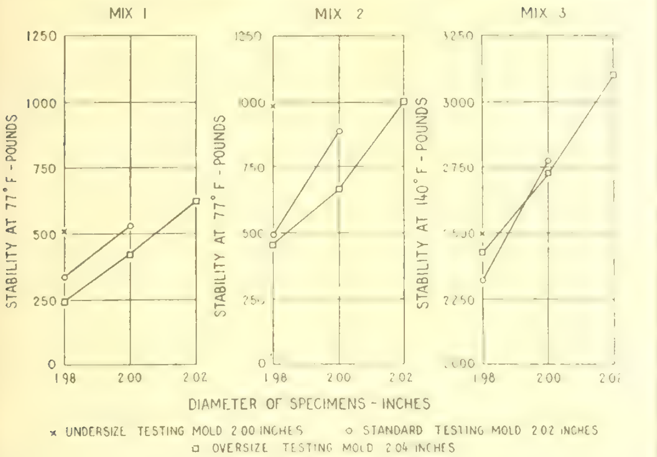

Figure 3.—Effect of Specimen Diameter Upon the Stability of Specimens, Using Standard Ring and Different Size Testing Molds.

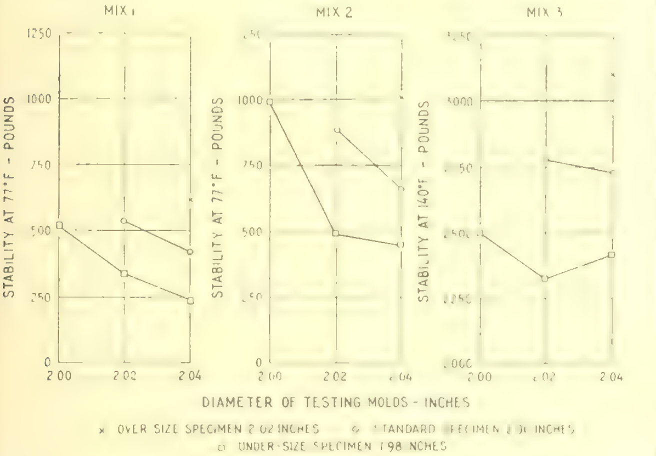

Figure 4.—Effect of Testing Mold Diameter Upon the Stability of Different Size Specimens, Using Standard Ring and Different Size Cylinders.

mold, the testing mold, and the testing ring. The bottom plates of the plungers were of different sizes but the study did not involve this variable. In forming the specimens the plunger used corresponded to the size of the forming mold, and in testing the specimens the plunger used corresponded to the size of the testing mold.

Stability test values were obtained on three mixtures. Mix 1 consisted of 7.4 percent slow-curing liquid asphalt, grade SC–3, and 92.6 percent Potomac River sand. Mix 2 contained 7.4 percent slow-curing liquid asphalt, grade SC–3, 14.0 percent limestone dust, and 78.6 percent Potomac River sand. Mix 3 contained 11 percent 50–60 penetration asphalt, 13 percent limestone dust, and 76 percent Potomac River sand. Each cylinder was molded under a pressure of 3,000 pounds per square inch, and the pressure was released immediately after the cylinder was formed. Mixes 1 and 2 were compressed at room temperature, and mix 3 at 300° F. Mixes 1 and 2 were tested in air at 77° F., and mix 3 in water at 140° F. after being in a water bath at 140° F. for 1 hour. All of the specimens of each mixture were made and tested in the same manner to insure uniformity. The results are given in table 2 and are shown graphically in figures 3, 4, and 5. All values are the averages of three tests.

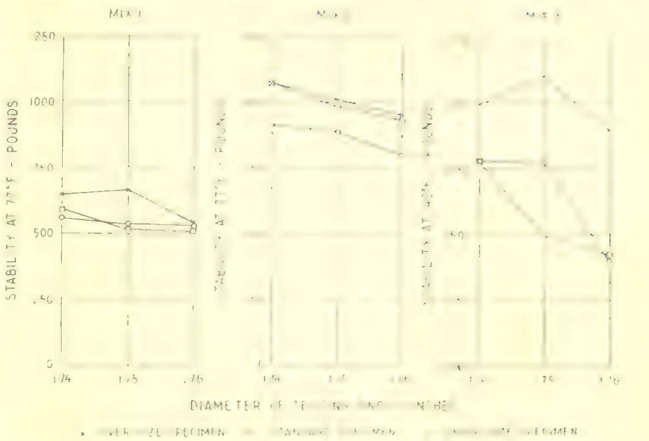

Figure 5.—Effect of Testing Ring Diameter Upon the Stability of Specimens Tested in Molds Giving 0.02-inch Clearance.

Table 2.—*Hubbard-Field stability values using different size molds and testing rings*

Diameter of forming mold and specimen (inches)	Diameter of ring	Stability of mix 1,[1] using testing molds of—			Stability of mix 2,[1] using testing molds of—			Stability of mix 3,[2] using testing molds of—		
		2.00-inch diameter	2.02-inch diameter	2.04-inch diameter	2.00-inch diameter	2.02-inch diameter	2.04-inch diameter	2.00-inch diameter	2.02-inch diameter	2.04-inch diameter
	In.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
1.98	1.74	590	360	260	1,070	550	480	2,775	2,275	2,300
	1.75	520	330	240	980	490	450	2,500	2,325	2,425
	1.76	510	320	210	930	440	420	2,425	2,100	2,275
2.00	1.74	......	570	460	......	910	740	......	2,775	2,700
	1.75	......	540	420	......	880	660	......	2,775	2,725
	1.76	......	530	370	......	800	610	......	2,400	2,675
2.02	1.74	......	......	600	......	......	1,070	......	......	3,000
	1.75	......	......	620	......	......	1,010	......	......	3,100
	1.76	......	......	540	......	......	950	......	......	2,900

[1] Tested in air at 77° F.
[2] Tested in water at 140° F.

Different combinations of molding and testing equipment gave stability values ranging from 210 to 620 pounds for mix 1, from 420 to 1,070 pounds for mix 2, and from 2,100 to 3,100 pounds for mix 3.

Figure 3 shows the effect upon stability of varying the diameter of the specimens using the standard ring and the 3 different sizes of testing molds. It is seen that with a particular testing mold the stability increases as the diameter of the specimen increases.

Figure 4 shows the effect upon stability of varying the diameter of the testing mold using the standard ring and the 3 different sizes of specimens. For mixes 1 and 2 the larger the testing mold for a given size of specimen the less the stability. For mix 3 (the hot sheet asphalt mixture) there is the same general trend but to a much less degree, indicating that for mixtures of this type the diameter of the specimen (as shown in figure 3) is more important than the diameter of the testing mold. The difference in behavior of mix 3 is probably caused by the greater stiffness or stability of the hot-type mixture and its greater ability to withstand deformation without rupture.

Figure 5 shows the effect of varying the size of the testing ring upon the stability of the three different sizes of specimens tested in molds having a clearance of 0.02 inch. It is seen that, generally, the larger the testing ring the less the stability value.

The results obtained in this study show that it is highly important to have and maintain standard-dimensioned equipment. The forming and testing mold and the testing ring, which wear appreciably, should be checked frequently and replaced when there are appreciable differences from standard dimensions. It may be practical to reduce wear by providing specially hardened testing and forming molds.

(Continued from p. 37)

6. Of the total property taxes expended on all roads and streets—

(*a*) 11.5 percent was expended on State and State-aid roads.

(*b*) 38.8 percent was expended on local town roads.

(*c*) 49.7 percent was expended on urban streets.

7. Of the total motor-vehicle imposts expended on all classes of roads and streets—

(*a*) Motor-vehicle owners in rural areas paid 21.5 percent, and these same rural owners performed 23.8 percent of the total travel on all classes of roads and streets.

(*b*) Urban motor-vehicle owners paid 78.5 percent, and performed 76.2 percent of the total travel.

8. Of the total motor-vehicle imposts (including nonresident fees) expended on all classes of roads and streets—

(*a*) 96.1 percent was expended on State and State-aid roads.

(*b*) 3.9 percent was expended on local town roads.

Highway Bridges in New Hampshire.

Table 28.—*Comparison of taxation and expenditures in 1932*

COMPOSITION OF EACH $1,000 OF TAXES

Type of tax	Collected from residents of –	Amount	Percentage of total in each group
General property taxes	Rural areas	$158.06	26.2
	Places to 2,499	97.13	16.1
	Places 2,500 to 14,999	140.57	23.3
	Places 15,000 to 74,999	107.99	17.9
	Manchester	99.54	16.5
	Total	603.29	100.0
Motor-vehicle taxes	Rural areas	41.83	21.5
	Places to 2,499	37.74	19.4
	Places 2,500 to 14,999	45.33	23.3
	Places 15,000 to 74,999	25.68	13.2
	Manchester	25.87	13.3
	Nonresidents	18.09	9.3
	Total	194.54	100.0
Miscellaneous taxes	Rural areas	50.14	24.8
	Places to 2,499	33.56	16.6
	Places 2,500 to 14,999	52.16	25.8
	Places 15,000 to 74,999	32.95	16.3
	Manchester	33.36	16.5
	Total	202.17	100.0
	Grand total	1,000.00	----

COMPOSITION OF EACH $1,000 OF EXPENDITURES

Expended for—	Source of funds expended	Amount	Percentage of total in each group
Highways on State system	Rural areas	$38.39	17.6
	Urban areas	95.61	43.8
	Nonresidents	15.39	7.0
	Federal aid	13.11	6.0
	Loans and reserves	55.91	25.6
	Total	218.41	100.0
Local town roads	Rural areas	23.80	47.6
	Urban areas	22.05	44.1
	Loans and reserves	4.15	8.3
	Total	50.00	100.0
Urban streets	Urban areas	54.20	100.0
	Total all highways and streets.	322.61	--------
Education	------	269.44	--------
Public benefit	------	348.68	--------
Government	------	59.27	--------
	Grand total	1,000.00	----

9. Of all imposts and taxes (including Federal aid and loans and reserves) expended on all roads and streets—

(*a*) 67.7 percent was expended on State and State-aid roads.

(*b*) 15.5 percent was expended on local town roads.

(*c*) 16.8 percent was expended on urban streets.

10. Of all current imposts and taxes paid by residents, expended on all roads and streets—

(*a*) Rural property and motor-vehicle owners paid 34.1 percent, and travel by rural vehicles made up 23.8 percent of the total travel on all classes of roads and streets.

(*b*) Urban property and motor-vehicle owners paid 65.9 percent, and travel by urban vehicles made up 76.2 percent of the total travel.

STATUS OF FEDERAL AID HIGHWAY PROJECTS

(1936 FUNDS)

AS OF MARCH 31,1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 263,237	$ 180,341	26.6	$ 1,673,657	$ 1,389,049	74.5				211,957
Arkansas	2,142,723										2,142,723
California	4,756,959	206,821	119,044	6.1	4,209,334	2,415,171	60.3	$ 1,105,519	$ 628,637	46.0	1,594,107
Colorado	2,288,811	287,306	160,891	15.8	1,807,311	1,007,974	70.0	315,649	176,764	6.7	943,182
Connecticut	791,253							1,174,399	563,149	13.8	228,104
Delaware	609,375				206,807	101,608	25.1	277,175	138,587	13.1	369,179
Florida	1,655,723				674,678	337,339	23.8	358,922	179,461	12.5	1,138,923
Georgia	3,168,221				979,489	459,220	74.6	1,491,550	745,775	80.5	1,963,226
Idaho	1,531,162	292,520	164,327	44.6	1,375,596	821,063	121.9	298,909	163,410	11.8	382,362
Illinois	5,160,696				4,666,683	2,330,987	82.3	2,432,660	1,216,330	38.1	1,613,379
Indiana	3,037,613	244,408	122,199	6.9	4,803,278	2,397,783	155.9	1,045,479	522,531	38.9	45,100
Iowa	3,231,718	224,362	105,460	57.5	4,110,350	1,937,090	186.3	1,916,160	899,268	70.5	289,900
Kansas	3,317,054	52,698	26,349	50.0	1,310,980	655,490	206.6	2,492,125	1,246,062	203.4	1,389,153
Kentucky	2,304,143	604,406	302,203	39.4	1,564,765	762,800	102.3	1,450,355	690,896	37.7	548,243
Louisiana	1,776,939	107,553	53,777	3.7	1,352,478	676,239	49.2	1,168,144	584,072	38.5	462,852
Maine	1,090,167	113,605	56,802	2.1	1,504,065	752,033	49.6	155,387	77,694	2.4	203,638
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877				333,935	166,968	3.1				1,574,909
Michigan	3,837,292	1,028,185	512,595	33.2	3,772,718	1,883,634	139.2	2,309,750	1,154,875	92.3	286,188
Minnesota	3,423,306	334,238	143,116	12.2	2,966,580	1,249,666	180.1	2,058,312	1,020,575	210.6	1,009,950
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,140,975	570,486	221.1	3,176,422	1,588,211	121.2	356,013	178,007	27.8	1,464,152
Montana	2,560,449	691,680	387,271	141.9	1,898,601	1,063,027	128.2	1,686,878	944,483	144.9	165,668
Nebraska	2,581,663	1,106,650	553,325	66.5	644,552	341,638	68.2	11,054	5,527	5.2	1,681,173
Nevada	1,595,501	235,206	202,733	74.0	764,980	662,243	77.3	218,163	188,863	15.8	541,662
New Hampshire	609,375				672,702	330,042	20.9	229,839	114,803	3.2	164,530
New Jersey	1,675,751				2,011,338	1,005,669	29.9	1,428,197	627,568	10.5	42,514
New Mexico	1,999,299	159,058	96,739	18.4	2,023,923	1,237,084	147.0	313,717	134,452	10.2	471,024
New York	6,150,106				8,381,855	4,147,300	155.3	1,698,295	834,772	23.7	1,168,034
North Carolina	2,938,657	87,050	43,525	15.2	1,067,113	532,967	174.4	1,113,156	534,603	138.7	1,827,562
North Dakota	1,960,162										1,960,162
Ohio	4,565,435				1,327,482	662,642	18.5	4,289,210	2,004,315	54.2	1,898,478
Oklahoma	2,947,521				1,745,438	914,973	58.1	613,749	325,678	20.8	1,706,870
Oregon	2,044,633				2,634,877	1,605,062	94.4	451,672	275,520	10.1	164,051
Pennsylvania	5,348,062	60,985	30,492	1.5	4,164,592	2,082,296	58.1	3,216,248	1,607,329	47.4	1,627,945
Rhode Island	609,375										609,375
South Carolina	1,692,896				50,787	25,393					1,667,503
South Dakota	2,036,775				516,850	283,389	35.2	564,135	309,315	90.3	1,444,072
Tennessee	2,638,159	43,106	21,553	1.8	1,222,959	611,479	56.5	303,467	151,734	7.1	1,853,393
Texas	7,777,504	1,195,545	596,803	76.2	6,388,108	3,181,513	350.2	3,654,859	1,822,795	190.1	2,176,393
Utah	1,410,752	271,124	193,299	17.0	1,047,630	755,811	73.8	449,219	289,827	26.8	171,814
Vermont	609,375	25,987	12,994	2.9	1,123,469	561,734	51.7	52,043	26,022	4.7	8,625
Virginia	2,278,475				655,424	327,712	23.3	1,885,804	942,902	68.2	1,007,861
Washington	1,949,957	663,093	349,200	20.5	2,073,342	1,090,619	56.2	227,411	119,700	6.9	390,438
West Virginia	1,356,793	87,161	43,581	3.0	540,732	270,366	29.1	323,877	161,938	12.6	880,908
Wisconsin	3,045,557	511,344	255,672	18.9	1,571,688	783,251	70.6	895,274	447,637	30.9	1,558,997
Wyoming	1,559,444	607,457	373,686	88.8	1,881,479	1,143,672	185.8	46,782	23,391		18,695
District of Columbia											
Hawaii	609,375				67,469	33,734	.5	203,132	99,148	3.0	476,493
TOTALS	121,875,000	10,645,760	5,678,463	1,065.8	84,966,516	44,585,941	3,689.2	44,294,689	22,238,415	1,869.9	49,372,181

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MARCH 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Work Program Funds	Miles	Estimated Total Cost	Work Program Funds	Miles	Estimated Total Cost	Work Program Funds	Miles	
Alabama	$ 4,151,115				$ 2,698,507	$ 2,698,507	81.1	$ 964,019	$ 964,019	29.8	$ 488,589
Arizona	2,569,841	$ 136,011	$ 136,011	14.1	1,631,836	1,501,604	92.8	637,139	388,242	46.6	543,984
Arkansas	3,352,061				1,568,730	1,596,479	119.3	1,176,188	1,174,804	139.4	580,778
California	7,747,928	30,260	28,100	10.1	5,305,350	5,010,851	182.2	479,907	468,943	25.7	2,240,034
Colorado	3,395,263	53,764	53,764	4.5	1,607,074	1,606,683	77.8	112,476	112,476	4.7	1,622,340
Connecticut	1,418,709							316,706	294,778	.2	1,123,931
Delaware	900,310				345,599	345,599	23.5	224,484	224,484	35.2	330,227
Florida	2,597,144				1,014,196	996,324	38.0	1,139,823	1,139,823	35.4	460,998
Georgia	4,988,967				433,342	433,342	29.0	303,348	303,348	19.3	4,252,277
Idaho	2,222,747				1,042,354	1,039,713	87.7	372,993	358,166	26.4	824,868
Illinois	8,694,009	9,995	9,995	.2	4,175,577	4,175,577	189.5	2,583,264	2,583,264	208.7	1,925,173
Indiana	4,941,255				2,191,828	2,191,828	131.2	2,607,368	2,607,368	130.9	142,059
Iowa	4,991,664	15,034	14,100	6.6	1,034,315	986,365	73.3	1,628,129	1,547,334	224.2	2,443,865
Kansas	4,994,975	11,478	11,478	6.1	2,235,197	2,235,197	213.7	2,213,699	2,213,699	154.9	534,601
Kentucky	3,726,271				1,339,320	1,339,320	202.0	1,342,320	1,327,303	119.8	1,059,648
Louisiana	2,890,429				395,582	281,189	10.3	507,991	469,947	40.3	2,139,293
Maine	1,676,799				702,709	702,709	33.4	775,394	774,847	32.7	199,243
Maryland	1,750,738							509,659	454,385	22.2	1,296,353
Massachusetts	3,262,885							117,600	117,600	1.1	3,145,285
Michigan	6,301,414	449,100	449,100	25.4	5,070,971	5,010,941	229.9	702,600	702,600	31.0	138,773
Minnesota	5,277,145	55,973	55,973	37.5	1,289,272	1,198,354	83.8	2,648,258	2,265,076	620.5	1,757,743
Mississippi	3,457,552				1,856,276	1,853,183	93.9	1,068,697	1,068,697	98.6	535,672
Missouri	6,012,652	96,002	96,002	59.0	2,233,645	2,233,409	440.3	1,771,853	1,770,408	299.0	1,912,833
Montana	3,676,416				2,261,052	2,261,052	126.1	1,162,030	1,162,030	59.3	253,334
Nebraska	3,870,739				1,427,201	1,386,437	144.1	1,438,815	1,438,654	159.9	1,045,648
Nevada	2,243,074	62,541	62,541	.2	1,599,234	1,559,664	64.8				620,868
New Hampshire	945,225				233,939	231,856	7.9	311,609	249,792	16.0	463,577
New Jersey	3,129,805				1,691,035	1,691,035	12.9	35,084	35,084	.4	1,403,686
New Mexico	2,871,397				1,575,662	1,575,662	119.4	720,881	720,881	51.5	574,853
New York	11,046,377				4,478,648	4,422,658	33.4	4,480,250	4,246,340	66.2	2,377,379
North Carolina	4,720,173				1,928,434	1,916,385	165.8	1,154,815	972,956	53.6	1,830,832
North Dakota	2,867,245	140,150	140,150	20.8	332,221	332,221	48.8	552,102	552,102	85.5	1,842,772
Ohio	7,670,815				2,004,581	1,993,581	23.0	2,186,200	2,079,075	29.2	3,598,159
Oklahoma	4,580,670				907,736	907,736	68.9	2,149,892	2,149,892	232.7	1,523,043
Oregon	3,038,642				1,748,967	1,738,967	67.0	592,727	569,629	71.0	730,046
Pennsylvania	9,347,797				164,017	164,017	.1	1,733,822	1,666,252	52.3	7,517,529
Rhode Island	989,208				109,796	109,796	4.0	689,152	689,152	13.4	190,261
South Carolina	2,702,012				681,043	670,920	65.3	809,174	809,059	74.8	1,222,034
South Dakota	2,976,454	79,687	79,687	30.1	618,289	618,289	166.7	921,857	921,857	147.8	1,356,621
Tennessee	4,192,460				908,199	908,199	39.5	1,151,228	1,151,228	42.3	2,133,032
Texas	11,989,350	39,435	38,931	15.4	6,934,526	6,307,729	573.3	4,135,191	4,101,506	435.6	1,541,183
Utah	2,067,154	51,885	51,885		793,615	768,254	74.0	438,381	399,763	26.5	847,252
Vermont	924,306				394,961	384,733	9.9	474,090	419,128	9.3	120,444
Virginia	3,652,667	53,677	53,677	49.6	1,262,499	1,262,499	576.0	1,149,976	1,137,974	287.2	1,198,517
Washington	3,026,161	696	696	.1	2,341,943	2,117,926	124.1	410,296	365,297	20.5	542,242
West Virginia	2,231,412				649,251	649,251	33.7	694,688	694,688	20.9	887,473
Wisconsin	4,823,384	60,230	50,000	1.3	2,027,265	1,721,598	88.5	2,474,535	2,392,066	195.5	660,220
Wyoming	2,219,155				1,635,961	1,635,948	93.4	263,359	263,355	31.4	319,852
District of Columbia	949,496	258,054	258,054	2.1	606,950	582,920	5.5	145,000	97,862	.9	10,660
Hawaii	926,033				568,853	551,400	7.5	100,588	98,812	1.4	275,821
TOTALS	195,000,000	1,603,972	1,590,144	283.1	77,957,558	75,907,907	5,146.3	54,579,657	52,716,044	4,531.7	64,785,905

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MARCH 31, 1936

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Fund	NUMBER		
				Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise	
Alabama	$ 4,034,617					$ 2,167,509	$ 2,167,509	24		$ 1,506,287	$ 1,506,287	11	5	$ 360,820
Arizona	1,256,099	$ 47,412	$ 47,412	1		735,478	594,908	7		78,841	69,907	1		543,872
Arkansas	3,574,060					955,193	951,595	23		1,101,468	1,099,563	21		1,522,902
California	7,486,362					6,018,361	5,774,181	35						1,712,181
Colorado	2,631,567					1,063,497	1,048,497	18		47,045	47,045			1,536,024
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					1,216,947	1,214,636	10		443,384	443,384	5		1,169,862
Georgia	4,895,949					10,581	10,581			344,859	344,859	5		4,540,510
Idaho	1,674,479					726,573	726,573	11		125,517	125,517	1		822,388
Illinois	10,707,184					1,511,362	1,511,362	14		3,323,599	3,323,599	37		5,466,223
Indiana	5,111,096					1,689,625	1,683,625	14		1,565,800	1,566,800	7		1,859,671
Iowa	5,600,679	7,303	7,000	1		935,220	894,250	14		[illegible]	[illegible]	36		[illegible]
Kansas	5,246,258					2,266,050	2,266,050	21		2,251,909	2,251,909	27	1	[illegible]
Kentucky	3,672,387					660,096	634,785	7		2,057,492	[illegible]	13		[illegible]
Louisiana	[illegible]									1,391,013	1,055,252	14		[illegible]
Maine	1,426,861					198,193	197,860	4		402,429	403,429	9		[illegible]
Maryland	2,061,751									1,025,247	1,002,773	7		[illegible]
Massachusetts	4,210,833					626,871	626,871	3		329,368	329,368	3		3,254,595
Michigan	6,765,137					4,359,152	4,359,152	34		876,600	876,600	7		1,529,445
Minnesota	5,395,441	103,407	103,407	2		559,500	553,450	7		770,009	770,009	25	2	3,968,575
Mississippi	3,241,475					890,483	890,483	18		904,083	904,083	21		1,446,909
Missouri	6,142,153					1,189,763	1,189,763	5		3,098,234	3,084,966	19		1,867,423
Montana	2,722,327					1,949,919	1,949,919	33		656,984	656,984	4		115,424
Nebraska	3,556,441					1,052,409	1,052,409	34		1,077,347	1,077,347	30		1,426,685
Nevada	887,260					306,096	306,096	7		75,872	75,872	1		505,292
New Hampshire	822,434					140,766	140,766			81,765	81,765			599,953
New Jersey	3,983,826									1,057,036	1,057,036	5		2,926,790
New Mexico	1,725,286	136,191	136,191	3		353,056	353,056	5		201,451	189,279			1,046,750
New York	13,577,189					3,687,636	3,463,336	9		3,235,005	3,130,659	14		6,916,194
North Carolina	4,823,958	10,268	10,268			930,988	930,988	10		455,713	455,713	8		3,426,989
North Dakota	3,207,473					164,184	164,184	4		258,732	258,732	10		2,784,557
Ohio	8,439,897					126,593	126,598			711,950	701,950	7		7,611,349
Oklahoma	5,004,711					1,057,893	1,057,893	21		706,747	700,717	11		3,246,101
Oregon	2,334,204					833,873	833,334	9		710,887	710,887	6		[illegible]
Pennsylvania	11,453,613					323,493	307,350	6		2,083,463	2,044,373	47		[illegible]
Rhode Island	694,691					465,562	445,236	2		229,226	211,334	2		[illegible]
South Carolina	3,059,956					794,350	791,047	17		283,380	283,312	8		[illegible]
South Dakota	3,249,086					178,741	178,741	4		405,517	405,517	6		[illegible]
Tennessee	3,923,979					343,591	343,591	9		265,741	265,741	4	3	[illegible]
Texas	[illegible]	9,076	9,076	1		1,869,795	1,860,339	29		3,590,335	2,773,794	36		[illegible]
Utah	[illegible]					326,200	326,200	4		247,869	194,391	4		[illegible]
Vermont	729,857					432,826	431,467	5		79,497	79,497	4		[illegible]
Virginia	3,774,287					224,389	224,389	4		1,181,965	1,107,617	33		[illegible]
Washington	3,095,041					1,722,370	1,717,570	19	1	35,317	[illegible]	1	6	[illegible]
West Virginia	2,677,937									194,541	194,541	2		2,483,396
Wisconsin	[illegible]					1,601,820	1,539,085	14		870,714	870,714	10		[illegible]
Wyoming	[illegible]	55,366	55,365	2		20,412	20,412			225,835	225,835	2		[illegible]
District of Columbia	[illegible]					166,697	166,697	2		253,264	[illegible]	1		[illegible]
Hawaii	[illegible]					153,695	153,695	2		[illegible]	[illegible]	1		155,817
TOTALS	[illegible]	363,023	358,719	10		47,018,811	46,196,527	518	1	42,286,771	[illegible]	[illegible]	17	[illegible]

U. S. GOVERNMENT PRINTING OFFICE: 1936

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Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

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TECHNICAL BULLETINS

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Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

No. 191 . . . . Roadside Improvement. 10 cents.

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An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

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MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF MARCH 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Work Funds	1935 Public Work Funds	Mileage	Estimated Total Cost	1934 Public Work Fund	1935 Public Work Fund	Mileage	1934 Public Work Funds	1935 Public Work Fund	Mileage	1934 Public Work Fund	1935 Public Work Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,152,602	$ 8,146,647	$ 2,683,285	730.3	$ 1,134,359	$ 186,798	$ 1,002,762	44.2		$ 309,254	3.4	$ 36,488	$ 264,541
Arizona	5,211,960	2,641,935	8,682,522	5,203,929	2,383,026	540.6	268,654		183,967	5.3		26,345	.3	8,031	48,597
Arkansas	6,748,335	3,428,049	10,208,185	6,561,060	2,681,466	571.4	625,747	63,188	541,502	35.2	$ 19,709	148,283	13.0	104,377	56,798
California	15,607,354	7,932,206	28,050,215	15,601,832	6,512,172	751.9	2,405,566		1,272,495	21.4		115,553		5,522	31,986
Colorado	6,874,530	3,486,006	11,101,259	6,831,431	3,446,085	636.4	6,817		6,500					43,099	33,421
Connecticut	2,865,740	1,454,868	4,183,331	2,825,079	942,214	69.3	411,623		396,102	3.8		30,000	.9	40,661	86,551
Delaware	1,819,088	923,395	2,645,496	1,819,088	782,660	128.3	32,528		32,528			108,207	1.6		
Florida	5,231,834	2,661,343	8,247,565	5,183,399	1,851,433	281.6	621,026		557,669	25.6		160,538	3.1	48,435	91,702
Georgia	10,091,185	5,113,491	11,764,660	9,085,816	2,233,108	673.9	1,593,050	456,333	1,086,693	73.3	257,556	632,826	56.4	289,481	1,160,864
Idaho	4,486,249	2,277,486	6,291,559	4,402,467	1,479,676	489.0	674,429		673,241	9.7	59,759	63,355	2.9	24,023	61,215
Illinois	17,570,770	8,921,401	21,560,235	15,666,055	5,287,859	606.3	4,897,431	1,788,987	3,006,031	88.5	3,838	338,573		111,891	288,938
Indiana	10,037,843	5,088,963	12,853,678	9,456,898	2,860,958	390.4	2,417,003	388,159	1,974,222	95.4	66,419	192,513	[illegible]	126,367	61,270
Iowa	10,055,660	5,118,761	15,218,322	9,939,405	4,684,613	1,214.2	297,801	114,154	162,100	4.9		226,800	5.0	2,101	44,848
Kansas	10,029,604	5,117,675	14,211,437	9,961,226	3,868,871	1,088.9	1,289,628	39,153	1,223,762	43.3	73,575	7,496	2.2	[illegible]	17,547
Kentucky	7,517,359	3,818,311	10,660,629	6,976,085	2,918,908	760.5	1,149,356	463,762	604,912	45.3	29,243	205,532	8.3	48,269	88,899
Louisiana	5,828,591	2,963,932	7,841,967	5,147,837	2,075,443	214.4	1,174,871	608,584	566,287	35.6	10,666	138,375	.4	61,504	183,827
Maine	3,369,917	1,711,586	4,924,578	3,340,131	1,370,913	184.8	283,470		283,456	8.3				29,786	57,218
Maryland	3,564,527	1,810,058	4,322,625	2,792,426	598,990	113.3	1,163,202	706,936	450,722	31.3		261,564	8.3	65,166	498,782
Massachusetts	6,597,100	3,350,474	7,007,820	4,587,052	1,833,767	104.3	3,071,060	1,896,850	1,174,210	11.0		2,247		113,198	340,250
Michigan	12,736,227	6,452,568	18,272,868	12,543,316	4,585,914	675.9	2,018,575	163,400	1,797,498	92.1		30,825	.1	29,511	38,631
Minnesota	10,656,569	5,425,551	15,390,124	9,876,724	4,764,364	1,622.6	845,761	646,206	188,445	25.9	8,060	212,158	1.8	125,579	260,583
Mississippi	6,978,675	3,540,227	10,482,165	6,080,931	1,693,357	609.0	2,560,938	771,411	1,595,941	127.9	4,437	184,058	11.8	121,836	66,872
Missouri	12,180,306	6,173,740	15,078,574	10,891,759	3,240,954	1,360.5	4,414,720	1,185,562	2,840,249	90.8		63,032		102,986	29,505
Montana	7,439,748	3,769,734	11,022,861	7,179,659	3,190,727	1,006.2	614,655	159,632	455,023	24.8				100,457	123,984
Nebraska	7,828,961	3,964,364	12,369,405	7,730,625	3,377,897	992.0	732,366	65,281	457,313	42.0		120,283	9.2	33,056	8,870
Nevada	4,545,917	2,302,356	6,681,743	4,490,286	1,950,891	736.0	352,903	26,150	290,647	21.7		25,429		29,481	35,338
New Hampshire	1,909,839	969,462	2,940,316	1,909,443	904,716	77.2	28,026		28,026	.5		5,000		396	31,720
New Jersey	6,346,039	3,220,879	6,832,962	6,001,676	473,165	74.9	2,751,538	175,941	2,258,664	12.4		303,276	6.6	168,421	185,774
New Mexico	5,792,935	2,941,700	8,498,814	5,632,432	2,660,013	766.5	151,694		151,694	1.1	114	38,369	.9	160,389	91,624
New York	22,330,101	11,327,921	37,178,864	21,577,255	9,123,381	799.8	3,165,750	553,400	2,063,799	25.2	145,025	70,200	1.2	54,421	70,540
North Carolina	9,522,293	4,840,941	14,237,986	9,048,263	3,973,687	1,320.8	718,643	122,138	579,610	20.3	35,078	208,644	4.3	316,815	79,000
North Dakota	5,804,448	2,938,967	7,274,966	5,484,037	1,140,639	1,949.5	788,804	131,259	598,949	112.4	67,289	585,157	76.5	121,863	614,221
Ohio	15,484,592	7,865,012	22,540,793	15,268,020	5,580,171	748.8	2,280,266	158,521	2,016,366	43.4	11,000	102,949	3.5	47,051	165,526
Oklahoma	9,216,798	4,685,180	13,226,023	9,060,692	3,245,249	774.0	1,194,282	147,071	1,045,476	30.6		153,826	1.9	9,034	240,629
Oregon	6,106,896	3,097,814	9,482,453	5,956,043	2,653,769	461.8	323,223	30,834	264,264	3.6	53,642	89,057	3.3	66,377	90,725
Pennsylvania	18,891,004	9,590,788	27,264,863	17,886,622	8,122,157	981.5	1,597,854	736,539	775,268	76.8	5,126	307,672	2.1	262,716	385,692
Rhode Island	1,998,708	1,014,572	2,982,260	1,998,708	850,540	88.0	138,587		137,102	1.1		880			26,050
South Carolina	5,459,165	2,770,954	7,100,723	5,240,709	1,687,463	578.5	701,931	32,110	627,862	39.6	11,220	32,100	.6	175,126	423,529
South Dakota	6,011,479	3,047,643	8,496,141	5,763,253	2,178,615	1,471.1	484,072	15,396	468,676	52.8	69,251	297,093	27.9	163,579	103,259
Tennessee	8,492,619	4,302,991	12,285,857	8,279,094	3,126,545	472.5	1,024,546	212,200	715,945	11.6		321,191	9.0	1,325	139,310
Texas	24,244,024	12,291,253	34,137,110	23,373,968	9,145,819	2,696.2	3,992,452	786,031	3,002,600	81.9	23,000	30,831	15.1	61,024	112,003
Utah	4,194,708	2,132,691	6,960,549	4,156,356	1,861,919	584.0	327,904	6,060	267,191	6.9		1,500		32,291	2,081
Vermont	1,867,573	948,007	3,035,441	1,863,531	847,927	137.6	109,059	3,922	90,873	2.4		4,750		121	4,456
Virginia	7,416,757	3,765,387	11,222,211	7,174,592	3,135,607	573.0	483,296	112,885	362,960	44.2	55,648	28,232	2.9	73,633	238,588
Washington	6,115,867	3,106,412	8,824,867	6,098,534	2,504,487	292.7	574,946		568,849	10.1		1,727		17,333	31,350
West Virginia	4,474,234	2,280,335	5,502,877	4,314,485	988,343	186.6	1,051,184	115,848	881,403	31.9		293,744	4.2	43,902	116,845
Wisconsin	9,724,881	4,941,837	14,783,815	9,677,528	4,254,058	604.6	572,508	7,300	522,766	15.3		97,591		40,052	67,422
Wyoming	4,501,327	2,287,712	6,667,596	4,433,877	2,053,719	1,008.5	236,140	46,705	162,232	28.8		35,989		20,745	35,773
District of Columbia	1,918,469	973,842	2,570,032	1,909,584	660,313	19.5	313,125		277,625	2.9				8,885	35,904
Hawaii	1,871,062	949,778	1,885,014	1,510,686		40.0	1,465,742	351,635	914,171	15.6				8,740	35,607
TOTALS	394,000,000	200,000,000	569,158,958	375,945,871	144,471,853	33,259.6	59,593,111	13,478,341	41,606,348	1,678.7	1,009,655	6,613,084	290.9	3,566,133	7,308,715

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 3 ▽ MAY 1936

A STABILIZED SOIL ROAD IN VIRGINIA

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Issued by the

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Volume 17, No. 3 May 1936

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

STABILIZED SOIL ROADS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by C. A. Hogentogler, Senior Highway Engineer, and E. A. Willis, Assistant Highway Engineer

SOILS are unstable when the force required to displace them laterally under load exceeds their shear strength. Sliding of the soil particles follows. Failure of fills caused by slips, penetration of subgrade soil into the interstices of porous base courses, and the rutting of subgrades, base courses, and road surfaces are the results.

The purpose of soil stabilization is to provide road soils with enough abrasive resistance and shear strength to accommodate traffic under prevalent weather conditions, without detrimental deformation.

There are two general methods for accomplishing this.

1. By providing the soil with coarse and fine materials of the proportions and character required to produce stability, and possibly supplementing this by adding chemical admixtures to maintain the stability thus produced.
2. By incorporating water-insoluble binders in fine-grained or poorly graded soils, consolidating in a particular manner to provide structural stability, and covering the bases thus produced with thin wearing courses to furnish resistance to abrasion.

In either case the stability that can be obtained depends upon (1) the physical characteristics of the soil particles, (2) the cohesiveness of the binder, and (3) the strength and permanency of the joint that can be developed between soil particles and binder.

Methods of determining the properties of the various rock and soil materials used as aggregate, and such binders as bituminous materials and portland cement, have long been used as standard laboratory practice by the engineer.

ADSORPTION BY SOIL PARTICLES IMPORTANT FACTOR IN SOIL PHYSICS

With the development of information on soil stabilization, it has become more and more obvious that the adhesion that can be developed between aggregate and binder plays just as important a part in the performance of the resulting road surface, base course, or stabilized subgrade as the individual properties of binder and aggregate separately.

In such studies as well as those that may furnish a rational explanation of how water alone or water supplemented with chemicals effect soil stabilization, the engineer has had to enlarge his field of study to include investigations of the electrochemical phenomena of adsorption and base exchange long recognized in both agriculture and ceramics.

Adsorption, according to Bancroft (*2*)[1], is the phenomenon that causes all solids to tend to adsorb or condense on their surfaces any gases or vapors with which they are in contact. When adsorption involves reactions that are essentially chemical or ionic in character, it is termed base exchange. These phenomenon depend upon electrical attractions which may be illustrated as follows:

A piece of iron is attracted strongly enough by a magnet to cling to it and be lifted against the force of gravity. A piece of copper, in contrast, is not so attracted by the magnet. If the two metals were combined in varying proportions the magnet would be expected to attract the resulting alloys in varying degrees covering the whole range from none for the copper to a maximum for the iron.

Similarly all solids attract with varying intensity any gases, vapors, or even solids with which they are in contact. In the air solids adsorb films of air and, in saturated soils, the solids are covered with minute films of moisture. For a liquid to wet a solid in air, the liquid must displace the air film, and for this to occur the solid must attract the liquid more strongly than it attracts the air. Also, only materials that have greater affinity for air than for water can be thoroughly dried. Air is often adsorbed on soil solids so strongly after a period of drought that drops of rain will roll along on dust without wetting it.

Clay adsorbs different liquids to different extent, i. e., its power of adsorption is selective and under suitable conditions one liquid will displace another in contact with the clay. For this reason, a greasy dish is readily cleaned by rubbing it with wet clay, and grease may be removed from wool and cloth by rubbing it with dry clay. This use of dry clay is important industrially in filling cloth.

The power that plastic clays possess of retaining their plasticity when mixed with sand or other nonplastic material is caused by the adsorption of one solid by another. The clay is not distributed uniformly through the pores or interstices of the coarser particles but most of it forms a coating on the nonplastic material and many of the pores remain unoccupied even though there is more than sufficient clay to fill them.

BASE EXCHANGE DISCUSSED

A colloid that holds hydrogen adsorbed on its surface is termed a hydrogen-ionized or H-colloid. One with calcium adsorbed on its surface is termed a calcium-ionized or Ca-colloid. If a substance like hydrated lime $Ca(OH)_2$ is leached through soil containing H-colloids, the calcium replaces the hydrogen to form Ca-colloids and the hydrogen thus released combines with the released $(OH)_2$ to form water. The line of demarcation between selective adsorption and base exchange is often vague.

According to Searle (*28*) the theory of base exchange was first advanced in 1850. At this time and also in 1852, J. T. Way (*35*) reported that "* * * soils are able to remove ammonia from its solution, a fact appearing still more extraordinary inasmuch as there is no ordinary combination of ammonia in a state of insolubility in the soil." The removal of ammonia resulted from its replacing lime in the clay, the lime passing into solution. In 1858 Eichorn (*9*) showed that natural hydrated double silicates, known as zeolites and used largely as water softeners, have this property of exchanging one base for another.

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[1] Italic numbers in parenthesis refer to bibliography, p. 64.

In 1912 Weigner (*36*) showed definitely that base exchange of silica gel has all the characteristics of an exchange adsorption process. The amount of cations adsorbed is mathematically related to the concentration of the surrounding solutions at equilibrium.

Turner (*34*) working with tropical soils was able to evaluate the exchange capacities both of the organic matter and of the clay. Bradfield (*4*), in 1923, supplied information on the types of acids that occur in soils. Arrhenius (*1*), in 1926, found that the adsorption of dyes by clay is related to their molecular weights, the materials having the higher molecular weights being adsorbed to the greater extent.

Work by Dr. Hans Winterkorn and Dr. L. D. Baver (*3, 39*) has done much to substantiate and supplement the findings of the earlier investigators on the effects of the chemical characteristics of the soil upon its physical properties.

The performance of the soil mass is so largely dependent upon the character of the contained moisture that the subject of soil physics almost completely resolves itself into a study of the physical properties of soil moisture.

Water may be of two kinds—adsorbed or free—as concerns its adhesion to soil particles. It may be gravitational, capillary, cohesive, or solidified, depending on the performance of the water or the properties it imparts to the soil mass.

In colloidal suspensions, the soil particle may be considered as being encased in a film of electrically adsorbed water, or water of hydration, and suspended in a body of free water as illustrated in figure 1.

Free water has the freezing point, the boiling point, the surface tension, and the viscosity of ordinary water. Adsorbed films, in contrast, have higher boiling points, lower freezing points, greater surface tension, and are more viscous than free water.

It may be considered that the properties of the outermost layer of adsorbed films of water are more nearly like those of free water, and that the properties of the innermost layer are more nearly like those of solidified water or ice. Within the thickness of the film all the properties from those of free water to those of ice would then be represented.

The extent to which the free water and film water influence the performance of soils depends upon both the moisture content of the soil and the surface area of the soil particles. The lower the moisture content at equal grain size and the finer the soil at equal moisture content, the greater will be the influence of the adsorbed water.

Gravitational water is free water drawn into soils by gravity during rains and thaws. Capillary moisture is free water drawn up through the pores of a soil above the water table by capillary force. When the film or skin covering the surface of water is penetrated by an object such as a glass tube having greater attraction for water than for air, a water film proceeds upward and wets the tube above the surface of the liquid. The adjacent water covering, which is part of the adhesive film, is pulled upward until the weight of water in the meniscus thus formed equals the tensile strength of the film.

Bigelow and Hunter, who, according to Meinzer (*22*), were apparently the first investigators to make direct measurements of the capillary rise in tubes other than glass, concluded that the capillary ascension of water is different in tubes of different substances and that it is probably a "* * * measure of the adhesion between the liquid and the substance in the wall."

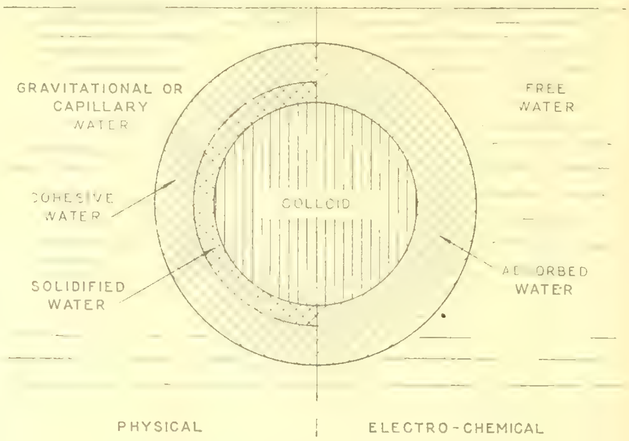

FIGURE 1.—COLLOID ENCASED IN FILM OF ADSORBED WATER AND SUSPENDED IN FREE WATER.

For equal pore size, the greater the adhesive attraction the higher will be the capillary rise, the maximum height being limited by the surface tension of water. For equal adhesive attraction, the height of capillary rise and the corresponding adhesion of the films increases as the diameters of the pores decrease.

SOLIDIFIED WATER FILMS CAUSE PLASTIC SOILS TO FORM HARD CLODS

To illustrate how changes in the properties of water affect the performance of soils, assume that a small amount of soil is shaken up thoroughly in water so that the soil particles are dispersed throughout the water. If the resulting soil suspension is set aside, the soil particles will gradually settle to the bottom and form a sediment. The porosity, or moisture content, of this sediment at first is so high that the sediment has all the properties of a fluid, i. e., due to its own weight it will deform and acquire the shape of any vessel in which it is placed, and it has buoyant properties such that its density may be measured with a hydrometer. At this consistency the soil has a high moisture content and, in turn, the ratio of free water to adhesive water is great, so that the performance of the mixture is dominated by properties of free water.

As the moisture content of the soil is reduced the consistency becomes that of slips and slurries which also deform under their own weight to assume the shape of any vessel in which they are placed. However, the soil no longer has the buoyancy of a fluid and its density can no longer be determined with a hydrometer. At this consistency, the soil can be said to be in the viscous state. The minimum moisture content of the soil in this state is the true lower liquid limit of the soil, although the test constant, the liquid limit as determined by the Atterberg test and discussed below, is somewhat less.

When the moisture content is reduced below the true lower liquid limit, the consistency of plastic soils is so changed that they become pastes that require the application of external pressure in order to undergo change in shape. The ratio of lubricating to adhesive moisture, while decreasing, is still sufficiently great to cause the properties of the soil to be dominated by the lubricating water.

Upon further reduction of moisture, a moisture content is reached at which the properties of the soil are altered abruptly from those of a plastic paste to those of a semirigid material with a correspondingly abrupt and considerable increase in its bearing value. This results from the fact that the ratio of lubricating to adhesive moisture becomes so reduced that the adhesive water abruptly becomes the dominating influence on the performance of the soil. This moisture content is the plastic limit of the soil.

On continued evaporation, the soil acquires a maximum density due to this evaporation. The moisture content at this density is the shrinkage limit of the soil. Further reduction of moisture below the shrinkage limit is not accompanied by further reduction in volume. Continued evaporation below the shrinkage limit causes the mobile moisture to recede in the pores leaving only the very thin, more or less solid films, which may have thicknesses of only a few millionths of an inch.

When all of the pore moisture is finally evaporated, the adhesive films are reduced to a solidified state with molecular thicknesses. Such films are really ice since at the enormous pressures (estimated greater than 20,000 atmospheres) under which they exist the melting point of ice is, according to the Smithsonian physical tables (*29*), in excess of 76° C. or 168° F. It is because of these solidified water films that thoroughly dried plastic soils form cakes and clods instead of dust.

Means of providing a strong and lasting joint between soil particles and the adhesive films connecting them include the use of admixtures and compaction.

NUMEROUS ADMIXTURES USED IN SOIL STABILIZATION

The kinds of admixtures and the means by which they effect soil stabilization are summarized as follows:

1. Mineral aggregates and soil constituents of the character and sizes required to make graded mixtures stable.
2. Moisture-retentive chemicals, such as calcium chloride and common salt, to provide soil binders with enough moisture to facilitate the compaction of graded mixtures by traffic.
3. Solutions of electrolytes, such as calcium chloride, common salt, sodium hyposulphite, etc., to reduce the thickness of adhesive water films on soil particles and thus provide stabilized mixtures with greater density.
4. Primes and fillers such as soaps, stone dust, and slag to increase the adhesion between mineral constituents and the chemical and bituminous admixtures and thus assist in retaining the benefits the admixtures were expected to furnish.
5. Neutralizers such as limestone dust, slag, hydrated lime, etc., that serve to alkalize acid soils and thus prevent the loss of stabilizing chemicals caused by detrimental base exchange.
6. Water-insoluble binders, such as portland cement and bituminous materials, to furnish films more substantial than those of moisture alone and to destroy permanently the colloidal properties responsible for detrimental volume change in soil mixtures.

The effect of admixtures on the density of stabilized soil may be illustrated by means of tests devised by R. R. Proctor (*25*). They are based on the fact that for each soil there is but one moisture content, termed the "optimum" moisture content, at which the maximum density is produced by a specific amount of compacting. For each density, each soil has a particular stability as indicated by the force required to penetrate the soil with a footing of known area at a given speed. When the soil is compacted to maximum density at optimum moisture content, the adsorptive attraction between water and soil particles is probably such that the tendency for moisture to enter the soil and expand or soften the soil mass is largely eliminated.

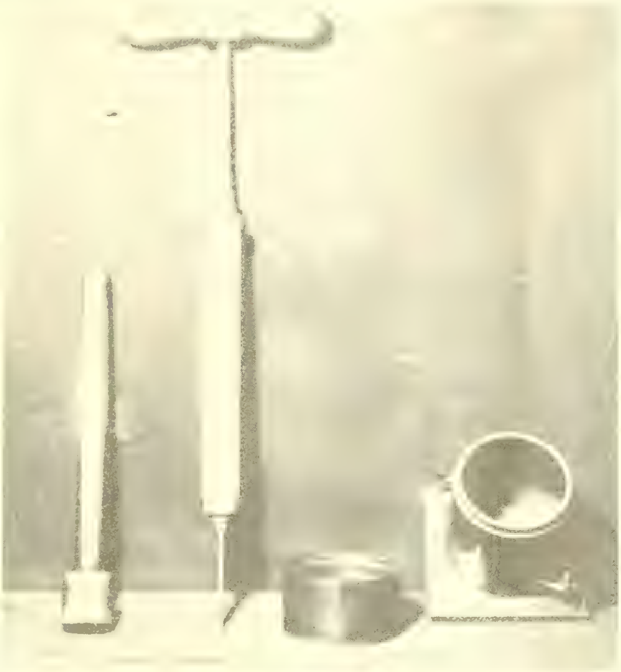

Figure 2.—Upper; The Proctor Compaction Test Apparatus. Lower; Measuring the Stability of a Sample in the Field.

The apparatus required for the compaction test consists of a brass cylinder 4 inches in diameter and about 4½ inches deep, which is mounted on a removable base plate and fitted with a detachable collar 2 inches high to hold the loose soil in place while compacting; a 5½-pound cylindrical rammer with an end area of about 3 square inches; and a plasticity needle of known end area. (See fig. 2.)

In the compaction test approximately 5 pounds of dry soil passing the no. 10 sieve are mixed thoroughly with just enough water to make it slightly damp and compacted in the cylinder in 3 layers, each layer receiving 25 blows from the rammer dropped a distance

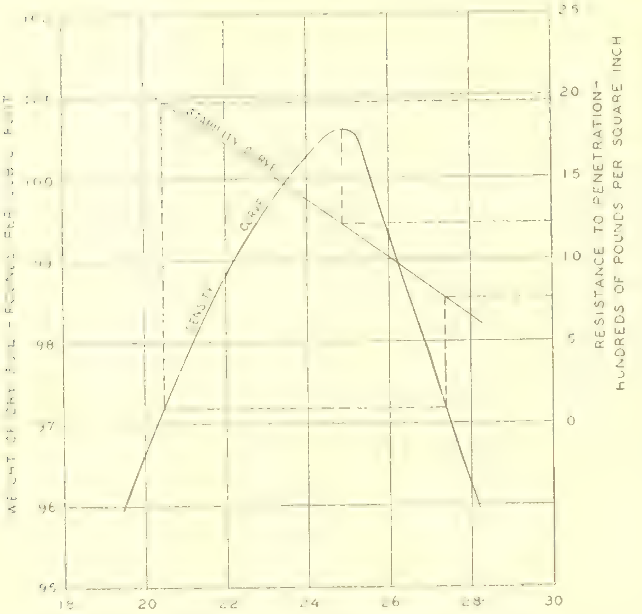

FIGURE 3.—EFFECT OF VARIATIONS IN MOISTURE CONTENT UPON THE DENSITY AND STABILITY OF A SOIL.

of 1 foot. The soil is then struck off to the level of the cylinder, weighed, and the stability determined with the plasticity needle by measuring the force required to force it into the soil at the rate of one-half inch per second. A small sample of the compacted soil is oven dried to determine the moisture content.

This procedure is repeated, each time adding about 1 percent more water, until the soil becomes very wet and there is a substantial decrease in the weight of the compacted wet soil. The effect of moisture on the densities of the compacted samples is shown by plotting the densities of the compacted soil when dry, expressed in pounds per cubic foot, against moisture content. The plasticity needle readings, expressed in pounds per square inch, are also plotted against moisture content to show the effect of moisture on stability.

Two curves resulting from the test (fig. 3) illustrate the significance of the compaction data. The dry-weight, moisture-content curve discloses that for this soil a moisture content of about 25 percent is required if maximum compaction is to be obtained. The corresponding stability is about 1,200 pounds per square inch.

If, at a specified density, the stability of this particular soil as indicated by the plasticity needle is higher than 1,200 pounds, the increase can be considered as only temporary if the soil is to be unprotected from water after construction. For this soil a stability of 1,950 pounds per square inch indicates a moisture content of slightly more than 20 percent. This corresponds to a dry weight of about 97 pounds per cubic foot. This density is representative also of a moisture content of slightly more than 27 percent which, in turn, corresponds to a stability of but 750 pounds per square inch.

TEMPERATURE IS A FACTOR TO BE CONSIDERED IN COMPACTING SOILS TO HIGH DENSITY

It is proverbial that molasses is "slower" in January than in June. The same can be said about water for it also is more viscous in cold weather. Because of this, sedimentation proceeds at a slower rate in cold water, the films of adsorbed water on soil particles are thicker, for equal degrees of compaction the moisture content of soil is greater, and for equal moisture contents the stability of soil is greater during periods of low temperature.

It can be shown by the application of Stokes' law that the times required for settlement through a depth of 20 feet of water at temperatures of about 100° F. and 35° F. would be respectively as follows: Coarse sand grains with diameters of 1.0 millimeter, 4.6 seconds and 11.4 seconds; silt grains with diameters of 0.01 millimeter, 12.8 hours and 31.6 hours; and clay particles with diameters of 0.001 millimeter, 53 days and 132 days. In these computations, only the increase in the viscosity of free water caused by the drop in temperature is considered.

The greater thickness of the adsorbed films is indicated by data furnished by Baver and Winterkorn (*3*) and shown in table 1. Here, the cubic centimeters of adsorbed films or hydration per gram of colloid is greater at low than at higher temperatures. Thus the Putnam colloids ionized with sodium have 5.25 cubic centimeters of adsorbed water film per gram at 30° C. and but 2.52 cubic centimeters at 99° C.

TABLE 1.—*Hydration*[1] *of Putnam and Wabash colloids as affected by temperature*

Temperature	Hydration in cubic centimeters of water per gram of colloid ionized with—		
	Sodium	Calcium	Hydrogen
	PUTNAM COLLOID		
°C.	*Cm³ per gram*	*Cm³ per gram*	*Cm³ per gram*
30	5.25	9.75	5.20
50	4.56	3.90	3.52
70	2.53	1.98	2.16
99	2.52	.86	2.70
	WABASH COLLOID		
30	7.45	6.74	17.95
50	6.29	6.14	16.08
70	5.09	6.44	14.79
99	3.67	7.10	9.70

[1] From viscosities.

The effects of temperature on the moisture contents, densities, and stabilities of soils compacted in the same manner are indicated by the curves shown in figures 4 and 5. The gradings and the physical properties of the soils used in the compaction tests discussed below are given in table 2.

The red clay and Iredell soils are representative of the clay soils conspicuous because of their high plasticity and volume change. The Arlington soil is a typical silt-loam soil. The Manor soil is a silty soil that contains enough mica flakes to cause the soil to be highly elastic.

Soil designations, such as Iredell, Manor, Putnam, and Cecil, used in this report are names given to particular series of soils formed under given conditions of weathering. The names generally indicate the locality (township or county) in which a particular series was first identified and mapped. Thus the Manor series is representative of a type first mapped in Manor Township, Lancaster County, Pa. The names are used here

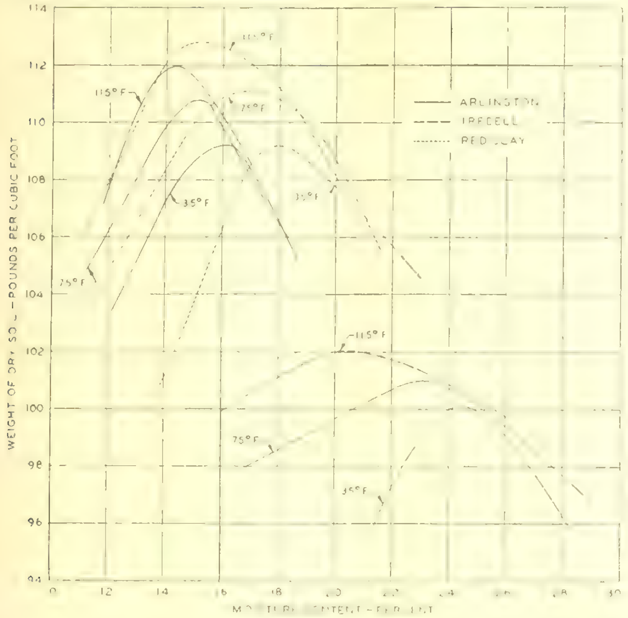

Figure 4.—Effect of Temperature upon the Density of Different Soils.

solely for the purpose of identification and not to denote physical characteristics.

In figure 4 are shown the dry-weight, moisture-content curves produced by equal amounts of compacting for three different soils as determined at three different temperatures. In all cases the maximum densities are higher and the optimum moisture contents lower, the higher the temperature at the time of test.

Table 2.—*Results of tests on different soils*

MECHANICAL ANALYSIS [1]

Soil	Particles larger than 2.0 mm	Particles smaller than 2 mm (percent by weight)					
		Coarse sand 2.0 to 0.25 mm	Fine sand 0.25 to 0.05 mm	Silt 0.05 to 0.005 mm	Clay smaller than 0.005 mm	Colloids smaller than 0.001 mm	Passing no. 40 sieve
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Red clay	0	4	8	20	68	51	98
Iredell	0	14	8	20	58	42	89
Arlington	0	6	27	36	31	22	99
Manor	0	7	42	39	12	8	98

PHYSICAL CHARACTERISTICS [1] OF MATERIAL PASSING NO. 40 SIEVE

Soil	Liquid limit	Plasticity index	Shrinkage		Moisture equivalent	
			Limit	Ratio	Centrifuge	Field
Red clay	65	47	10	2.0	31	25
Iredell	78	55	12	2.0	[2] 76	40
Arlington	27	7	19	1.7	33	21
Manor	37	11	38	1.4	22	42

[1] Determined in accordance with standard A. A. S. H. O. and A. S. T. M. testing procedures.

[2] Waterlogged.

Figure 5 shows the relations between the stability as measured by the plasticity needle and the temperature of the sample. Each curve is for a single sample compacted at high temperature and shows that an increase in stability occurred when the temperature was reduced, the moisture content and density remaining constant.

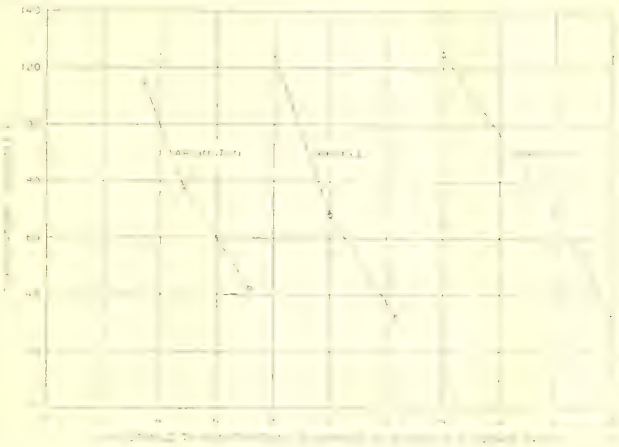

Figure 5.—Effect of Temperature upon the Stability of Different Soils.

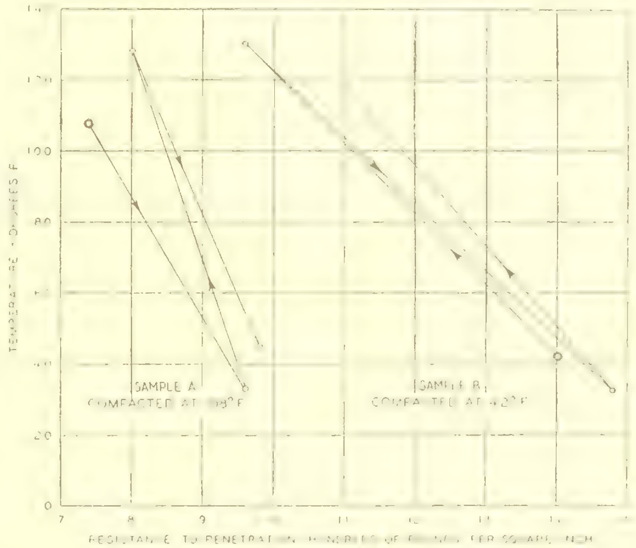

Figure 6.—Effect of Alternations of High and Low Temperature on the Stability of Red Clay Soil.

The sample of Iredell clay was compacted at a temperature of 125° F. and a moisture content of 24.6 percent (the optimum moisture content for a temperature of 35° F.). The temperature of the sample was then reduced first to 68° F. and then to 32° F. The stabilities were 800 pounds per square inch at 125° F., 1,000 pounds per square inch at 68° F., and 1,240 pounds per square inch at 32° F.

The stabilities of the other two samples (fig. 5), likewise were greater at the lower temperatures. The Arlington soil had a stability of 710 pounds per square inch at 42° F. as compared with 340 pounds per square inch at 115° F. For the red clay the stability was 2,000 pounds per square inch at 32° F. as compared with 1,400 pounds per square inch at 125° F.

The curves in figure 6 show that the phenomenon of change in stability with change in temperature is a reversible one, the stability increasing with lowering temperatures and decreasing with rising temperatures. In figure 6 the curve marked A shows the effect of compacting a sample at high temperature and then successively lowering and raising the temperature. The curve marked B shows the effect of compacting the sample at a low temperature and then successively increasing and decreasing the temperature. The sam-

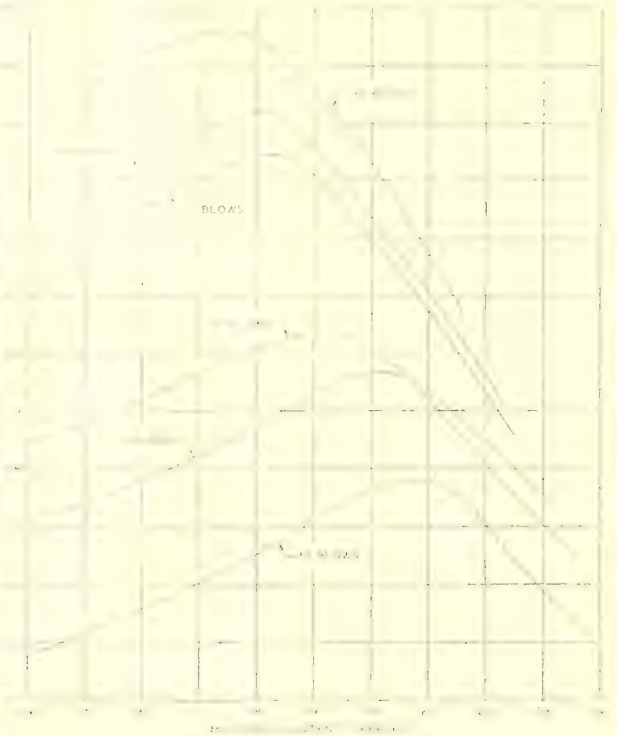

FIGURE 7.—EFFECT OF AMOUNT OF COMPACTING UPON THE DENSITY OF MANOR SOIL.

ples used in obtaining the information shown in figure 6 were not compacted at the optimum moisture content, and the moisture contents were not the same for samples A and B. This explains the differences in stability shown by the two curves.

Decrease in the temperature at constant moisture content causes a decrease in the free water and a corresponding increase in the adsorbed water. This decrease in the ratio of the lubricating to the adhesive moisture results in an increase in the relative viscosity of the total moisture, adsorbed and free. This increase is in addition to the increase in the viscosity of the free water caused by drop in temperature. The total variation in the viscosity of all contained moisture can be considered as the primary influence on the variation in density and stability with variation in the temperature of compacted soils.

The dry-weight, moisture-content curves in figure 7 show the effect of the amount of compacting the sample received upon its density. The curves show the results of varying the number of blows per layer in compaction tests of the Manor soil. The greater the number of blows per layer, the lower were the optimum moisture contents and the higher were the maximum densities of the compacted samples. Figure 8 shows the relation between the dry weights at optimum moisture contents and the number of blows per layer for the Manor soil.

PROPER GRADING OF MIXTURE IS A FIRST CONSIDERATION IN CONSTRUCTING STABLE SOIL ROADS

According to Dr. C. M. Strahan (*30*) the best graded soil mixtures can be expected to furnish roads that, when dry, are strong, hard, free from noticeable ruts, holes, or corrugations, possess a well-shaped crown, and drain freely into the side ditches. A thin layer of loose, sandy material may sometimes be present, but not sufficient in amount to impede traffic. During heavy rains or after long wet spells the surface should not be noticeably softened, but should remain practically nonslippery and free from appreciable mud. Driving speed may need to be only slightly reduced.

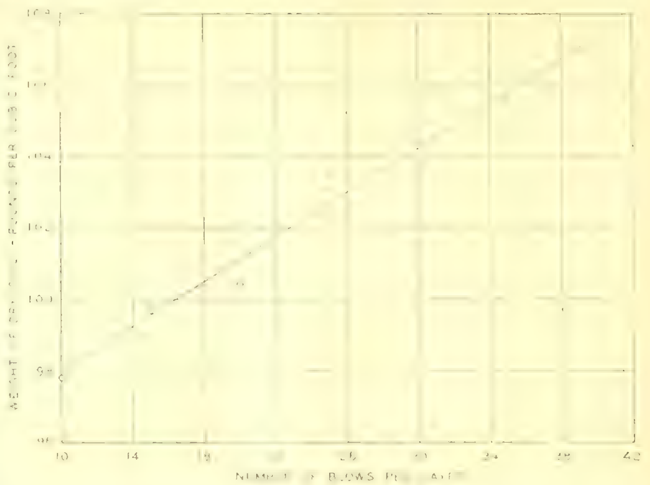

FIGURE 8.—EFFECT OF AMOUNT OF COMPACTING UPON THE DENSITY OF MANOR SOIL AT OPTIMUM MOISTURE CONTENTS.

Proportioning of soil materials for surface courses should provide:

1. Enough crushed rock, gravel, or slag retained on the no. 10 sieve to furnish the strength and hardness needed to resist the abrasive action of traffic.
2. Enough sand or other granular material passing the no. 10 sieve and retained on the no. 200 sieve to provide the interlocking of soil grains and thus increase the shear strength.
3. A quantity of silt and sand (particles 0.074 to 0.005 millimeters in diameter) to act as a filler and to provide the capillary bond necessary for stability when the binder clay loses cohesion in wet weather.
4. Enough clay (particles smaller than 0.005 millimeters in diameter) to retain the minute adhesive films after the larger films of capillary moisture have evaporated and thus provide the adhesion required to maintain stability during dry weather.

The abrasive resistance and the degree of interlocking of soil mixtures are indicated by the grading of the granular fractions. Materials falling within the following limits, by weight, satisfy the above requirements and should produce good surfacing layers:

Passing:	*Percent*
1-inch sieve	100
¾-inch sieve	85–100
No. 4 sieve	55–85
No. 10 sieve	40–65
No. 40 sieve	25–50
No. 200 sieve [1]	10–25

Material larger than 1 inch can be used under certain conditions but the amount should not exceed 10 percent. Also the maximum size should never exceed one-third the thickness of the stabilized layer. The

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[1] The smallest fraction of the grading determination referred to in previous reports was that passing the no. 270 sieve. The hydrometer method of analysis has been used to determine the fraction referred to as that passing the no. 270 sieve because that method is more practical than one using the no. 270 sieve. However, the use of the no. 200 sieve is practical. Furthermore, it has been found that a knowledge of the characteristics of the fraction passing the no. 200 sieve serves our purpose as well as a knowlege of the characteristics of the fraction passing the finer sieve and eliminates the necessity of making the hydrometer analysis. This explains the substitution of the no. 200 for the no. 270 sieve in the grading requirements.

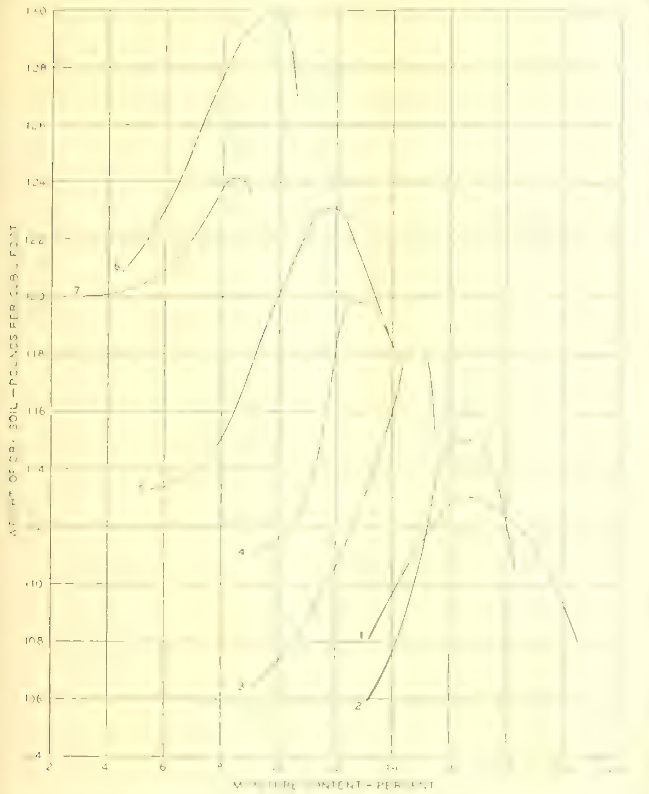

FIGURE 9.—EFFECT OF GRADING OF SAMPLES ON THE RELATIONS BETWEEN DENSITY AND MOISTURE CONTENT.

fraction passing the no. 200 sieve should be less than two-thirds of the fraction passing the no. 40 sieve.

For base courses the fraction passing the no. 200 sieve should be within the range of 0 to 25 percent and should be less than one-half of the fraction passing the no. 40 sieve.

The dry-weight, moisture-content curve for a soil passing the no. 10 sieve and meeting the requirements for a good soil mortar is shown in figure 9, sample 6. The grain size accumulation curve for this sample is shown in figure 10.

The effects of increasing the percentages of silt and clay are also shown in these figures. The data are summarized in table 3.

TABLE 3.—*Grading, optimum moisture contents, and densities of samples*

Sample number	Mechanical analysis									
	Passing no. 10, retained on no. 20	Passing no. 20, retained on no. 40	Passing no. 40, retained on no. 60	Passing no. 60, retained on no. 100	Passing no. 100, retained on no. 140	Passing no. 140, retained on no. 270	Silt	Clay	Optimum moisture content	Dry weight at optimum moisture content
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Lb. per cu. ft.*
1	1	1	2	4	2	2	20	68	16.7	113.0
2	0	1	1	2	1	1	60	34	16.5	115.0
3	0	1	0	2	14	25	37	21	14.7	118.3
4	0	1	0	22	11	19	30	17	12.9	119.8
5	0	0	22	18	9	15	23	13	11.8	123.1
6	24	16	13	10	5	9	15	8	9.6	129.8
7	28	18	14	11	6	10	13	0	8.5	124.1
8	24	16	14	10	6	7	5	18	8.9	129.3
9	0	25	20	15	7	10	5	18	10.4	126.9
10	0	0	29	23	12	13	5	18	11.8	123.8
11	0	0	1	36	18	22	5	18	12.8	120.4

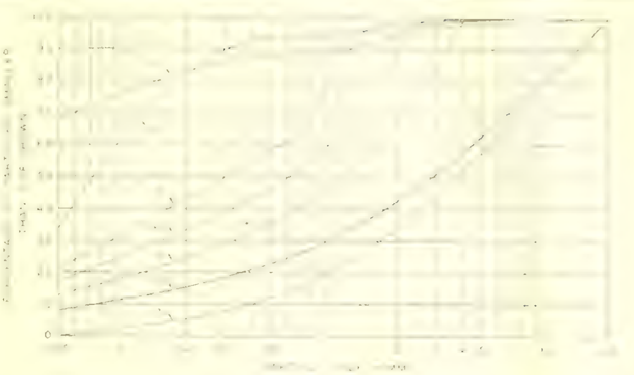

FIGURE 10.—GRAIN SIZE ACCUMULATION CURVES OF SAND ADMIXTURES.

The red clay, sample 1, contains 68 percent clay, 20 percent silt, and 12 percent sand. At the optimum moisture content of 16.7 percent the dry weight was 113.0 pounds per cubic foot as compared with a dry weight of 129.8 pounds at 9.6 percent optimum moisture content for the excellent soil mortar (group A–1 soil), sample 6.

Samples 2, 3, 4, and 5 were obtained by adding silt and sand to the red clay represented by sample 1. An attempt was made to obtain proportions representative of the different fractions of sample 6. Thus sample 5 represents approximately the grading of the fraction of sample 6 material that passes the no. 40 sieve; sample 4 represents the fraction that passes the no. 60 sieve; sample 3 represents the fraction that passes the no. 100 sieve; and sample 2 represents the fraction that passes the no. 270 sieve.

Figure 9 shows that as the total sand is decreased from that of sample 6 to that of sample 2 the density of the compacted mixtures decreases and the optimum moisture contents increase. In sample 7 an attempt was made to approximate the grading of the fraction of sample 6 that was larger than 0.005 millimeter. As would be expected in the absence of the clay fraction the optimum moisture content is smaller than that of sample 6, being only 8.5 percent. The maximum density, however, is but 124.1 pounds per cubic foot, which is 5.7 pounds per cubic foot less than that of the excellently graded material (sample 6).

In figures 11 and 12, data for sample 6 are compared with similar data for four samples in which the sand, silt, and clay fractions are constant but the grading of the sand fraction is varied. The maximum density of sample 8 with 5 percent silt and 18 percent clay and approximately the same sand gradation as sample 6 is slightly lower than that of sample 6. As the coarser sand fractions are eliminated from samples 9, 10, and 11 and the mixtures approach a more nearly uniform grain size, their densities decrease.

PHYSICAL AND CHEMICAL PROPERTIES OF AGGREGATE AND BINDERS MUST BE CONSIDERED

The aggregate of satisfactory stabilized mixtures should be hard and durable enough to resist weathering, traffic abrasion, and crushing. Sound, tough particles or fragments of gravel, stone, slag, or combinations of them, crushed to the proper size, should prove suitable. Certain types of shales and similar materials that break up and weather rapidly when alternately frozen and thawed, or wetted and dried, should not be used.

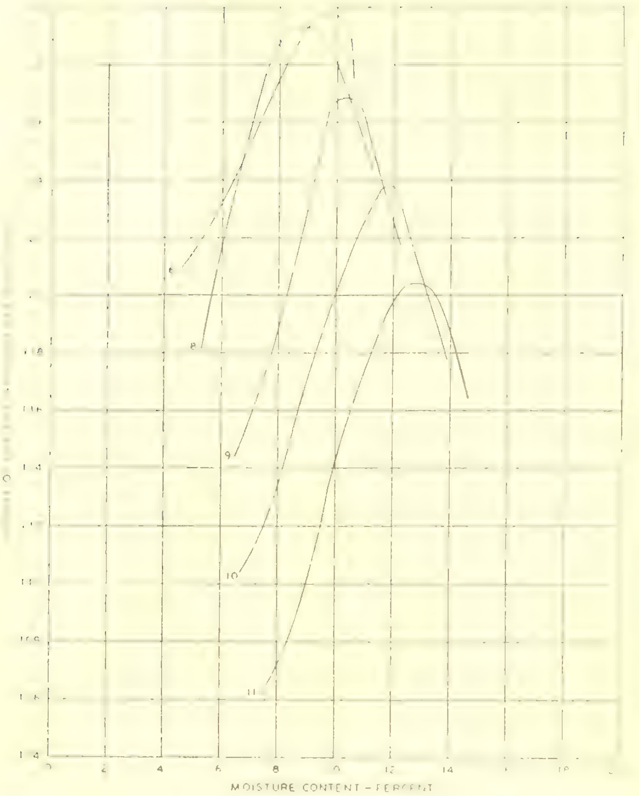

Figure 11.—Effect of Grading of Samples on the Relations Between Density and Moisture Content.

The soil fines should be of a character such as to provide graded mixtures with the proper balance of capillarity and cohesion without risk of detrimental volume change. Fines which swell enough in the presence of moisture to have moisture contents appreciably in excess of their plastic limits are likely to prove the least desirable. This is because the more the moisture content increases above the plastic limit, the more likely is clay to become a lubricant instead of a binder.

Just as the adhesive water instead of the free water becomes the determining influence when the moisture content of a soil is reduced from above to below the plastic limit, there is a corresponding opposite change when the moisture content of clays is raised from below to above the plastic limit. With this change the clay can be considered as changing from a binding to a lubricating medium as illustrated in figure 13. It will be noted that for a constant load, the deformation increases very slowly (about 0.00026 inch) for each 1 percent increase in moisture content, until a moisture content approximately equal to the plastic limit is reached. The lubricating effect of the moisture above this amount is indicated by the fact that the increase in deformation is thereafter about 100 times as great (0.022 inch) for each 1 percent increase in moisture content (*15*).

Finally, the surface characteristic of the entire mixture should be such as to provide satisfactory adherence of chemical or bituminous admixtures to the mineral particles and to prevent the occurrence of detrimental base exchange.

In addition to actual swell test data, such qualities as high plasticity, considerable shrinkage on drying,

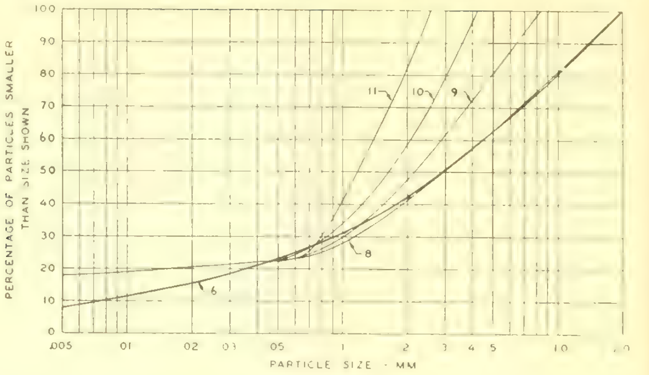

Figure 12.—Grain Size Accumulation Curves of Sand Admixtures.

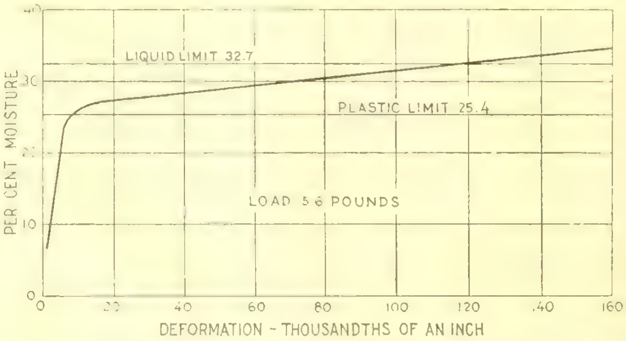

Figure 13.—Relation Between Moisture Content and Deformation for a Soil Sample under Constant Load.

high moisture equivalents, and the like, also indicate soils likely to undergo detrimental volume change.

The more acid the soil, the greater is its base exchange capacity, and consequently its corrosive properties. The relative acidity or alkalinity is disclosed by the concentration of the hydrogen ions.

Of the two parts of hydrogen and one of oxygen (H_2O) that comprise water, one part of the hydrogen (H) may be considered as positive, acid-producing ion; the other part of the hydrogen in combination with the oxygen (OH) may be considered as the negative, alkaline-producing hydroxyl. The pH value, which is used to indicate the concentration of hydrogen ions, equals the reciprocal of the logarithm of the grams of ionized hydrogen per liter of solution or suspension. Thus the total ionized hydrogen in grams per liter equals 10^{-pH}.

When the hydrogen and the hydroxyl are in complete equilibrium, as in distilled water, the pH value equals 7.0. The lower the pH value below 7.0 the greater is the acidity of the liquid. The higher the pH value above 7.0 the greater is the alkalinity of the fluid.

Figure 14 shows the relations between the depth of corrosion of metal pipes and the pH value of the soils in which the pipes are buried (*7*).

The physical characteristics indicative of swell, the pH values which disclose the relative acidity of soils, and the electrochemical characteristics that control the adhesion between aggregate and binder, depend largely upon both the chemical composition of the soil particles and the ions adsorbed on their surfaces.

In humid, northern climates, weathering may cause the iron and aluminum oxides to be leached from the soil, leaving relatively large accumulations of silica. In a humid tropical climate, in contrast, there is a tendency

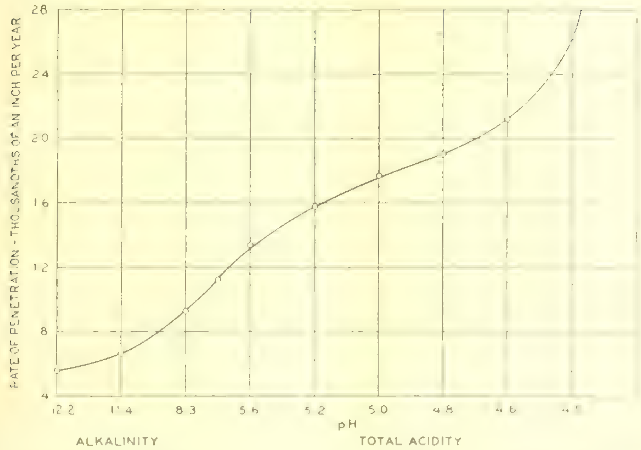

Figure 14.—Relation Between Acidity and Corrosion of Steel in Synthetic Soil.

for iron and aluminum compounds to accumulate. The ratio of silica to the combined iron and aluminum oxides is termed the silica sesquioxide ratio and is designated by the symbol "SiO_2/R_2O_3".[2]

Clays high in silica, termed "podsols", are acidic and consist principally of the highly water-adsorbent scale-like particles, that have high plasticity and shrinkage values. Soils high in iron and alumina, termed "laterites", are alkaline and consist more of the bulky or spherical particles.

Russell (*27*), in summarizing the work of previous investigators, states that the typical clay properties—plasticity, stickiness, power of swelling on moistening and of shrinkage on drying, and power of cementation—all increase as the SiO_2/R_2O_3 ratio increases from 2 to 6 or 7 (podsols) but do not usually appear when the ratio (SiO_2/R_2O_3) is 2 or less (laterites).

The greater swelling of soils with the higher SiO_2/R_2O_3 ratios, as found by Winterkorn and Baver (*3*), is shown in table 4.

Table 4.—*Influence of adsorbed ions on the water affinity of soil colloids*

Type of clay	$\frac{SiO_2}{R_2O_3}$	Swelling for ions of—					
		Sodium	Lithium	Potassium	Calcium	Barium	Hydrogen
		Cm³ per gram	*Cm³ per gram*	*Cm³ per gram*	*Cm³ per gram*	*Cm³ per gram*	*Cm³ per gram*
Bentonite	5.0	11.1	10.8	8.6	[illegible]	2.5	2.2
Putnam	3.2	4.0	5.0	.5	.9	.9	.8
Wabash	3.2	3.7	3.1	.6	.8	.7	.9
Iredell	1.8	.6	.4	.02	.3	.4	.2

ADSORBED IONS AFFECT PERFORMANCE OF SOILS

Research in base exchange by Joseph and Oakley (*19*) has shown that generally the plasticity and shrinkage were greatest in soils saturated with lithium ions. As the kind of adsorbed ions was changed successively to sodium, magnesium, calcium, potassium, ammonium, and hydrogen ions, the plasticity was gradually reduced.

The shrinkage was gradually reduced as the kind of adsorbed ions was changed successively to sodium, magnesium, calcium, hydrogen, ammonium, and potassium ions. The moisture equivalents were highest for the sodium-ionized clay and were reduced gradually as the kind of adsorbed ions was changed successively to lithium, magnesium, hydrogen, calcium, and potassium ions.

Joseph (*18*) gives an example of a sodium clay having a moisture equivalent double that of the calcium clay. The values were as follows: Natural soil, 69 percent by weight; sodium-ionized clay, 125 percent; and calcium-ionized clay, 63 percent.

The effect of adsorbed ions upon the swell and slaking values of clays as found by Dr. Winterkorn (*39*) is shown in tables 4 and 5.

According to Russell (*27*), the normal clay of fertile soils is a calcium clay, but the calcium can easily be replaced by other bases or by hydrogen; a new clay then arises. Two of these clays, the acid and the sodium, occur somewhat frequently in nature.

Table 5.—*Influence of adsorbed ions on slaking time*

Type of soil	$\frac{SiO_2}{R_2O_3}$	Natural soil	Time of slaking for soil having ions of—							
			Magnesium	Hydrogen	Potassium	Iron	Ammonium	Barium	Sodium	Calcium
		Min.	*Min.*	*Min.*	*Min.*	*Min*	*Min.*	*Min.*	*Min.*	*Min.*
Cecil	1.3	147	[illegible]	122	121	93	65	6	24	24
Hagerstown		15	[illegible]	26	35	15	20	[illegible]	341	[illegible]
Putnam	3.2	[illegible]	[illegible]		24	26			420	26

Additional information on these types of clay is furnished by Taylor (*31*) as follows:

> Since the clay fraction of a soil shows marked flocculation phenomena, it indicates that the clay particles are charged. The present conception is that the charge on the particle is negative, due to the anions of the clay, and surrounding them are the positively charged kations, the hydrogen, calcium, magnesium, potassium, and sodium. It is thus possible to have a series of clay types according to the kations present. The most important clay types are hydrogen clay, characteristic of an acid soil; calcium clay, the normal constituent of agricultural land and of silt carried and deposited in fresh water; and the sodium clay, which is the characteristic clay in salt and alkaline land. From the geological point of view, calcium clay and sodium clay are the most important, as they are characteristic of fresh water and marine conditions respectively. When a silt containing calcium clay is carried in suspension and deposited in water containing sodium chloride, the sediment will contain sodium clay as a characteristic constituent.
>
> Other methods by which sodium clay may be formed are: (*a*) the submergence of strata in sea water; and (*b*) by the capillary rise of sodium chloride solutions from a subsoil water table containing this salt in solution. These two latter modes of formation are characteristic of deltaic deposits. It will be seen, therefore, that sodium clay is a characteristic constituent of sediments formed under marine, estuarine, or deltaic conditions, and that calcium clay is only associated with fresh water sediments.

According to Taylor (*31*), the sodium clay remains flocculated in the presence of sodium chloride and is stable in the presence of an excess of that salt. On replacement of the salt solution with pure water, however, the rate of percolation decreases, the percolate becomes alkaline, and finally the sodium clay becomes impermeable.

Russell (*27*) states: "Sodium clay easily hydrolyzes * * *. It is very sticky, impervious to air, and dries into hard, large lumps which break down in water to a paste. It is difficult to work."

According to Searle (*28*), the more highly dispersed the hydrogen or H-clay, the more acid can it be at the optimum silica content.

According to Taylor (*31*), the properties of calcium clay differ considerably from those of sodium clay.

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[2] The symbol SiO_2/R_2O_3 stands for $SiO_2/(Fe_2O_3+Al_2O_3)$.

The hydrolysis of calcium clay is a much slower process and the calcium clay is flocculated in the presence of fresh water. It is neutral, pH value from 6.5 to 8.5, according to the amount of carbonic acid or calcium bicarbonate present, and holds more water in the air-dry condition than under wet conditions. It is less sticky, more permeable and therefore drains more easily.[3]

NEUTRALIZERS USED TO PREVENT BASE EXCHANGE IN SOILS

The best way to insure that detrimental exchange will not occur is to have the soil mixture alkaline. Limestone dust and granulated slag seem admirably suited for use as pretreatments or with other admixtures to neutralize or "sweeten" acid soils and thus prevent detrimental base exchange.

According to Russell (*27*) the action of calcium carbonate on the soil is, in principle, very like that of any other salt. The calcium replaces hydrogen or sodium in the clay, thus converting an acid or alkaline clay into the more usual calcium clay; it also replaces acidic hydrogen in humic acid, forming the so-called calcium humate or neutral humus.

Dr. Winterkorn's work (*39*) furnishes some idea of the amount of neutralizer which may be required through the determination of the exchange capacities for the various types of clays completely ionized with hydrogen. If complete replacement occurred, his data show the grams of replaceable hydrogen per 1,000 grams of colloid to be as follows: Bentonite, 0.95; Putnam clay, 0.65; Wabash clay, 0.78; Iredell clay, 0.35. It is hardly likely that any properly graded road surface would ever contain more than 5 percent of clay colloid as active as the Putnams. If this is true, then in a road surface 4 inches thick compacted to an initial density of 130 pounds per cubic foot, there would be but 19.5 pounds of colloid per square yard of road surface. In such case there would be $0.00065 \times 19.5 = 0.0127$ pounds of replaceable hydrogen.

The amount of neutralizer required to replace completely the hydrogen equals the molecular weight of the neutralizer divided by the valence of its metal times the amount of replaceable hydrogen.

The molecular weight of calcium carbonate ($CaCO_3$) is 100 and calcium has a valence of 2. The amount of calcium carbonate required to replace the 0.0127 pound of hydrogen then becomes $\frac{100}{2} \times 0.0127 = 0.64$ pound.

Dr. Winterkorn's work further suggested that in the absence of leaching, but 26.9 percent of the total available hydrogen would be exchangeable for calcium ions. Under this condition but 0.17 pound of calcium carbonate per square yard of the road surface referred to above would be required. However, inability to control the conditions under which base exchange occurs in road surfaces and bases, in a manner comparable to laboratory control, requires the amount of neutralizer to be considerably in excess of that indicated by the computations.

With highly acid conditions, a maximum of 5 pounds of stone dust or slag per square yard of road surface or base will probably suffice to prevent detrimental base exchange. A smaller amount of hydrated lime might also produce the desired result.

PRIMES AND FILLERS USED TO INCREASE SOIL STABILITY

Materials that effect a beneficial change in the electrical fields surrounding the surfaces of the mineral constituents may be used to advantage as primes when the natural soils have greater attraction for films of air, water, or natural gels than for those of the admixtures expected to provide stability. Particularly in the stabilization of such materials as the "blow" sands of Nebraska and the beach sands of Florida is it likely that films of natural gels would merit special consideration.

The effect of such primes on soils is similar to that produced by coating a metal with acid before the application of solder, or shellacking the knots before painting lumber.

Winterkorn (*38*), Reagel, and Schappler[4] have experimented with soap primes as means to increase the adhesion between soils and bituminous materials. The greater adhesion of the oil for the soil provided by the soap pretreatment was demonstrated when a heavy rain washed the oil from a commonly constructed earth-gravel-oil mixture but did not wash it from the soap-treated section. It was indicated also that different soaps may be desirable for different soils.

In 1932, Victor Nicholson (*24*) called attention to the effect of surface chemistry upon the stability of asphaltic pavements. He described one sheet asphalt pavement in Chicago in which the sand grains on the surface became partly white and bare of asphalt not long after construction, as contrasted with other pavements in which the asphalt adhered so tenaciously that they did not become white. The surface whitening occurred during the first summer after the pavement was laid and was as bad in places where there was no traffic as where automobiles traveled.

In 1927, Mr. A. W. Dow (*8*) stated that "If two pavement mixtures, alike in every way as to composition, voids, etc., are tested for stability, the one containing mineral aggregate with the highest adsorptive value will show the highest stability." In 1929 Prevost Hubbard (*17*) stated: "Indications point to the fact that whether or not adsorption is directly responsible, those sands with high adsorption values possess more pronounced stabilizing characteristics than those with relatively low adsorption values, so that the two may go hand in hand."

Included among the filler materials which Nicholson lists as having greater affinity for water than for asphalt are: Impure silica, gypsum, impure limestone and common clay. Among those with greater affinity for asphalt than water are pure limestone dust and hydrated lime.

Present indications are that both calcium chloride and common salt are retained longer in road mixtures containing limestone or slag. This suggests that as in the case of bituminous binders the lime materials have greater attraction for the chemical admixtures than the silica soils.

There is evidence that the fillers having the greatest attraction for the stabilizing admixtures tend to provide the entire mineral mixture with properties producing a stronger bond with the binder. In this respect fillers may perform an electrochemical as well as a mechanical function.

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[3] The above discussion concerns sodium- and calcium-ionized clays, found in nature or produced in the laboratory. How far it applies to chemically treated and thoroughly compacted road soil mixtures is not known. The ionized clays can come into existence only when water has completely leached out and replaced the chemical salts with which the clays may have been treated. Under no conditions then, are the properties of the sodium and calcium clays representative of the properties of the same clays which contain the calcium or sodium salts.

[4] See Stabilizing Sand and Gravel Surfaces, a paper presented before the Kansas Highway Conference, Manhattan, Kans., Feb. 5, 1934.

As early as 1910, Prevost Hubbard (*16*) described the effect of rock powders used to increase the bond in stone mixtures. Quotations from his book, Dust Preventives and Road Binders on this subject are as follows:

In another paper by Cushman on The Effect of Water on Rock Powders, the following conclusions are reached: (*a*) "When water comes in contact with most rock powders, immediate reactions take place, which are to a certain extent analogous to those which take place with cement and powdered glass." (*b*) "The microscope reveals an accumulation of amorphous material of a gummy appearance largely associated with the surfaces of the crystalline particles as the action of water proceeds." (*c*) "The effect of wet grinding is to increase the binding power or the cementing value of rock powders, and there are indications that the addition of small amounts of suitable electrolytes" (soluble inorganic salts, acids, and bases) "to the water will still further increase the action."

The last fact has a decided bearing upon the effect of blending different road-stones, one of which through being partially soluble is capable of reacting upon the other to produce binding films. It has been noticed in cases in which macadam roads were being constructed of hard material, such as granite or diabase, which are difficult to bond under the roller, that the surface quickly compacted and gave satisfactory results when treated with a top dressing of limestone screenings. This observation led Cushman and Hubbard to determine the cementing value of mixtures of these rocks with limestone as compared with the cementing values of the individual rocks. The results of a number of tests are given below and show conclusively that the addition of limestone to a feldspathic rock increases the binding power.

RESULTS OF TESTS OF THE CEMENTING VALUE OF GRANITE MIXED WITH LIMESTONE

Granite, serial no.	Limestone, serial no.	Cementing value		
		Granite	Limestone	Mixture
1431	1391	3	27	110
1432	1342	9	22	56
1435	1335	7	26	38
1435	1423	7	26	53
1574	1411	6	20	82

As the binding power of rock dusts is due to the decomposition or hydrolysis brought about by the action of water, it would follow that if this binding power can be increased by the addition of limestone it is caused by further decomposition of the material, brought about by the interaction of calcium hydroxide ($Ca(OH)_2$), resulting from the hydrolysis of the limestone particles. This is demonstrated by the following results obtained by determining the cementing value of a number of granites when treated with a small quantity of limewater, or calcium hydroxide solution.

RESULTS OF TESTS OF THE CEMENTING VALUE OF GRANITE MIXED WITH LIMEWATER

Serial no.	Cementing value		Serial no.	Cementing value	
	Alone	With limewater		Alone	With limewater
810	12	21	1276	11	31
811	6	16	1329	10	44
817	11	21	1398	6	18
893	12	16	1431	3	19
1008	35	45	1432	9	12
1192	14	27	1435	7	15
1275	16	39	1574	6	11

These results show in every case a considerable increase in the cementing value of granites so treated and would indicate that the addition of a small amount of lime might greatly improve the binding value of certain roadstones. Of course the addition of a sufficient quantity of lime would produce a mortar in which the bond due to the crystallization of calcium carbonate will cover up any actual increase in the cementing value of the stone treated. This effect will also be produced to some extent when even a small quantity of lime is employed, but results given by Lord, who applied the principles developed by Cushman for rock powders, show that when a sample of chert and one of clinker were so treated the increase in cementing value was greatly in excess of that produced by treating a chemically inert slag in a similar manner. These results are given below and indicate that the increase in cementing value is due to the formation of a hydrated silicate of lime.

Material	Mineral composition	Cementing value				
		Alone	With 1 percent CaO	With 4 percent CaO	With 8 percent CaO	With 13 percent CaO
Slag	Olivene and gehlenite	8	15	33	52	[illegible]
Chert	Amorphous quartz	6	9	22	[illegible]	2,000+
Clinker	Acid silicate	4	24	60	....	1,400

PLASTICITY TESTS IMPORTANT IN SELECTING BINDERS

Instead of the chemical tests, the liquid limit and the plastic limit tests performed on the fraction of soil passing the no. 40 sieve are used to determine the relative capillary and cohesive properties of soils to be used as binders.

The liquid limit (*LL*) is defined as that moisture content, expressed as a percentage of the weight of the oven-dried soil, at which 10 light shocks will just cause the soil to begin to flow.

The plastic limit is defined as the lowest moisture content, expressed as a percentage of the weight of the oven-dried soil, at which the soil can be rolled into threads one-eighth inch in diameter without the threads crumbling.

The numerical difference between the liquid and the plastic limits is defined as the plasticity index (*PI*).

High liquid limits may be caused by capillary moisture, cohesive films, or a combination of both. Cohesionless mica flakes, spongy diatomaceous earth, and colloidal clay could all have a liquid limit, say, of 200. When such is the case the liquid limit of various mixtures of these materials would also be 200. Thus colloidal clay could be added to cohesionless diatoms in increasing amounts so that every degree of cohesion would be represented within the limits of the two materials without change in the liquid limits.

This is not true for the plastic limits. In cohesionless materials there is no plastic limit, which means, at least theoretically, that the plastic limit is equal to the liquid limit.

If the colloidal clay is added to the diatoms in increasing amounts, the plastic limits of the mixtures will decrease until the minimum of possibly 35 is reached, the plastic limit of the pure colloidal clay. Thus for equal liquid limits, the lower the plastic limit the greater is the indication of the presence of cohesive films and of plastic clays which furnish cohesion.

How the percentage of soil binder together with the accompanying capillarity required to produce a desired plasticity can be determined by means of data furnished by the plasticity tests has been suggested previously in Public Roads (*12*). The amount of inert material required to reduce excessively high plasticity can also be determined from similar data.

Generally plasticity indexes of about 3 or less indicate sufficient binder cohesion for soil road surfaces to be constructed on locations subject to unusually wet conditions; indexes of 4 to about 8 for conditions of average moisture; and indexes of 9 to 15 inclusive only for the drier or the arid conditions. Plasticity indexes exceeding 15 indicate soils not suitable for soil road construction.

The presence of the undesirable micaceous substances and diatomaceous, peaty, or other organic substances is indicated by liquid limits greater than those indicated by the expression $LL=1.6\ PI+14$.

The more the liquid limits exceed such values, the more unsatisfactory the soil binder is apt to be because of detrimental sponginess and capillarity. Elimination of such properties in detrimental amount from the final road mixture may be accomplished by keeping the liquid limits below 35.

For base courses the material passing the no. 40 sieve should have a plasticity index of not more than 6 and a liquid limit of not more than 25. The plasticity index and the liquid limit should be determined from tests conducted in accordance with standard A. A. S. H. O. and A. S. T. M. procedures.

EFFECT OF DELIQUESCENT CHEMICALS AND SOLUBLE BINDERS DESCRIBED

Granular material and binder are affected differently by traffic. The vehicle wheels will sink into roads of either pure dry sand or soft sticky clay. However, granular particles have a tendency to compact, whereas clays never lose the tendency to displace under traffic and form ruts. When a small amount of clay is mixed with granular material, the effect of the vehicle wheels is to force the sand grains closer together. Because of this, topsoil, gravel, and similar roads can, under proper conditions of maintenance, be developed into the densest of surfaces by traffic action alone, provided the surfaces are kept slightly moist. When such surfaces are dry, the binder powders under traffic and not only forms dust but also permits raveling of the surface, which leads to surface roughness and eventually to complete disintegration.

If, however, such surfaces can be maintained in a damp or slightly moist state, the binder will prevent the separation of the granular particles and the shocks and blows produced by vehicle wheels then become effective in wedging the granular fragments into close association. Thus the coarser stone, the sand, and the binder are compacted into hard road surfaces. Binder clay present in amount only slightly in excess of that required to coat the sand grains is gradually forced to the surface of the roads as the granular fragments consolidate, especially during wet weather, and is gradually carried off in the form of dust or worked to the sides of the road by traffic. In this way the gradings required for high stability may be automatically attained.

The importance of maintaining the proper amount of moisture in the surface cannot be overstressed. Absence of moisture from soil road surfaces causes dust and raveling. Too much moisture causes rutting. The drier the road surfaces become between rains the wetter they become when it does rain. This is because extreme dryness causes small cracks to form in the clay binder through which rain water may enter and soften the interior of the road surface. Fissures do not form in damp surfaces of properly graded roads. Consequently water is shed from them without injurious effect.

It is the function of the deliquescent chemicals to assist in maintaining moisture in the surface. Calcium chloride is sometimes used for this purpose. Magnesium chloride might also be of benefit. Under certain conditions of humidity and temperature such materials have the property of absorbing moisture from the air and slowing up the rate at which soils lose moisture between rains. Under certain other conditions they have the property of releasing their chemically combined moisture to the surrounding soil.

Sodium chloride functions mainly to retain the moisture already present in the soil and as a soluble binder that acts as a cement because of an interlacing of salt crystals formed in dry weather.

As the partially dried road continues to lose water, the solution of sodium chloride in the surface becomes concentrated to the saturation point and fine crystals are deposited, forming a cohesive sealcoat of salt and fine aggregate that appreciably retards further evaporation. Additional strength and stability are obtained through the crystallization of sodium chloride within the pores of the compacted mass as evaporation slowly proceeds. This filling of the voids minimizes the shrinkage which commonly accompanies loss of moisture, and thus reduces the tendency for shrinkage cracks to form. The importance of diminution of shrinkage in this way will be realized when it is considered that any shrinkage of the clay binder causes it either to crack or pull away from the coarse aggregates and thus allow the latter to become dislodged under traffic.

Treatment with either calcium chloride or sodium chloride (common salt) effects a decrease in the volume change and an increase in the density and stability of graded road mixtures; the calcium chloride does this through electrolytic and deliquescent properties, and the sodium chloride through electrolytic and crystalline properties. Generally, the surfaces treated with sodium chloride are harder, with a dryer appearance and slightly more dust, than the surfaces treated with calcium chloride.

Because solutions of calcium chloride and sodium chloride have lower vapor pressures than does water, the evaporation of moisture from soil mixtures wetted with these salt solutions is definitely slower than from similar mixtures moistened with water. These salts in a stabilized road mixture therefore tend to conserve its moisture.

The value of this ability to conserve moisture is most apparent during compaction of the stabilized mat in which the salt has been incorporated. The plasticity of the clay component is maintained over a longer time, thus prolonging the period during which compaction is taking place and permitting compression of the aggregate into a denser mass, with thinner and consequently stronger and more lasting binding films than would otherwise be obtained.

Roads treated with calcium chloride or sodium chloride may become coated with a thin layer of mud during wet weather. However it is believed that much of this is the result of an excess of soil binder or the use of a binder having too much plasticity. Use of these chemicals will not prevent loss of stability caused by faulty proportioning of soil materials in the mix. Proper grading of soil materials is an essential requirement in the stabilization procedures involving the use of either calcium chloride or sodium chloride. However, studies of the performance of more than 150 miles of salt-treated roads and approximately 2,000 miles of calcium-chloride treated roads indicate that, when used with properly designed soil mixtures, these chemicals have an important place in the highway field.

In the construction of soil base courses for either bituminous surface treatments or higher type wearing

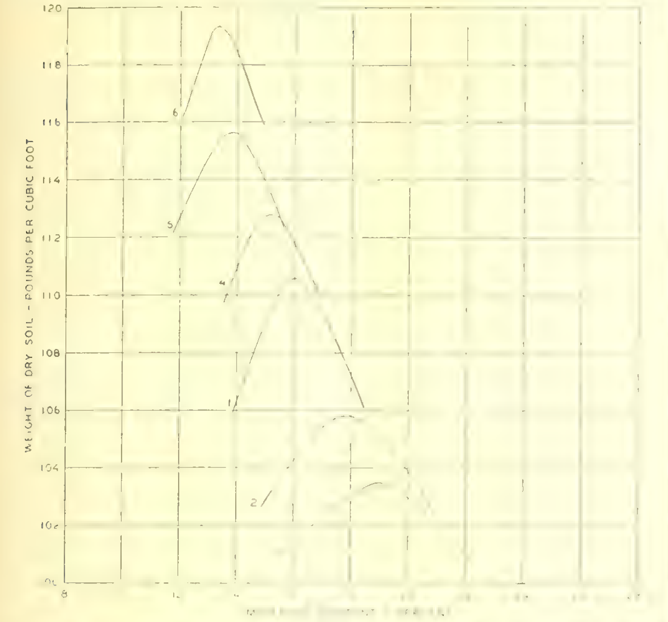

FIGURE 15.—EFFECT OF ELECTROLYTES AND FILLERS UPON THE DENSITY OF COMPACTED SOILS.

courses the use of chemicals may be of especial benefit. Soil mixtures for bases should have lower clay content than that required in stable surface courses. Compaction of such bases by traffic prior to the application of the surfacing is desirable. Only by the use of water-retentive chemicals can base mixtures lean in binder be kept from dusting and raveling excessively under traffic.

The effect of salt solutions as well as other materials on the density of compacted soils is illustrated in figure 15.

Curve 1, figure 15, shows the dry-weight, moisture-content relation for the Arlington soil with no admixture. Curve 2 shows the relation for the Arlington soil containing an admixture of 5 percent by weight of hydrated lime. Curve 3 shows the relation for the soil with an admixture of 2 percent by weight of sodium silicate. Curves 2 and 3 are both below and slightly to the right of curve 1. The dry-weight, moisture-content relations for the Arlington soil with admixtures of 5 percent by weight of ground slag, curve 4, 5 percent sodium chloride, curve 5, and 5 percent sodium hyposulphite, curve 6, are shown in figure 15 by curves above and to the left of curve 1. For curves 2 and 3 the optimum moisture contents are greater and the densities less than for curve 1; the opposite is true for curves 4, 5, and 6.

Table 6 summarizes the results of a series of tests made to determine the effect of various electrolytes and other admixtures upon the compacted densities of the three soils. Figure 16 shows the effect of the quantity of sodium chloride admixture upon the compacted densities of the Arlington soil.

INSOLUBLE ADHESIVES RENDER SOIL RESISTANT TO CAPILLARY MOISTURE

Portland cement and bituminous materials are the admixtures that have been experimented with and used most up to this time. Other admixtures that might prove satisfactory are dual treatments with sodium silicate and calcium chloride to produce insoluble calcium silicate, also dual treatment with ferric chloride and ammonia to produce the highly adhesive ferric hydroxide.

FIGURE 16.—EFFECT OF ELECTROLYTES UPON THE DENSITY OF COMPACTED SOILS.

TABLE 6.—*Effect of various admixtures on the optimum moisture contents and dry weights of various soils*

Soil admixture		Arlington		Iredell		Minot	
Kind	Amount	Optimum moisture content	Dry weight at optimum moisture content	Optimum moisture content	Dry weight at optimum moisture content	Optimum moisture content	Dry weight at optimum moisture content
	Pct.	*Pct.*	*Lb. per cu. ft.*	*Pct.*	*Lb. per cu. ft.*	*Pct.*	*Lb. per cu. ft.*
None	----	16.1	110.6	24.6	100.6	16.3	108.6
NaCl solution	5	13.8	115.8	18.4	109.6	14.5	112.4
$CaCl_2$ solution	5	14.0	115.4	20.8	107.5	15.2	112.2
Sodium hyposulphite	5	13.3	119.4	20.9	106.8	16.5	110.1
Hydrated lime	5	18.0	105.8	24.3	98.2	18.2	104.6
Soda ash	5	14.9	114.9	21.7	101.9	16.6	112.2
Sodium silicate	5	15.3	100.0	25.7	94.9	19.0	102.1
Ground slag	5	15.0	112.8	21.8	105.1	17.5	106.8
Ground limestone	5	16.8	110.0	18.9	105.3	16.8	107.2
Ferric chloride	5	14.5	115.5	22.8	102.9	17.5	109.0
Raylig[1]	5	11.9	114.1	23.0	98.5	13.8	109.0
Tannic acid	2	15.4	110.3	24.1	97.7	16.5	106.0
Cement	5	15.2	112.4	22.4	101.0	17.1	103.2
Bituminous material[2]	5	14.0	109.0	20.8	98.2	16.5	103.0

[1] Waste sulphite liquor.

[2] Applied in an emulsion.

In stabilization with insoluble adhesives, the fact that the films of adhesives might be thicker than those of moisture or solutions of electrolytes, at the same degree of soil compaction, has no significance with respect to the relative stability of the soil with the different films. The use of insoluble adhesives is not expected or intended to render the soil sufficiently hard or tough to resist the abrasive action of traffic, but simply to render the soil resistant to water from capillarity and thus to retain the same bearing strength that the soil has when in a dry, compacted condition.

In 1925 Goldbeck (*11*) reported the results of laboratory experiments which showed that additions of 5 percent of hydrated lime and portland cement have the effect of decreasing the volumetric change caused by variations in moisture content and likewise of increasing the bearing value of plastic soils that contain up to their limit of capillary moisture. The results of these tests are shown in figure 17.

Additional evidence that cohesive binders in soils are likely to prevent both their expansion and disintegration caused by water absorption resulted from tests that have been reported (*13*). Figure 18 shows six soil cakes representing soil existing at different depths in a subgrade located at Arlington, Va. The subgrade was treated with water-gas tar in 1923. These cakes were compressed in a semidry state, dried to constant weight, and immersed in water for 2 weeks in 1929. The two cakes shown on the left contained

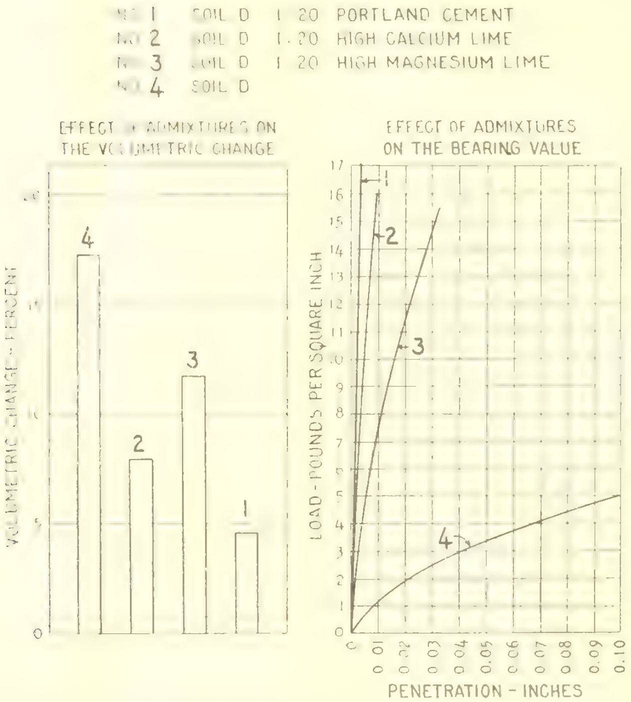

Figure 17.—Effect of Lime and Cement on Shrinkage and Bearing Value of a Soil.

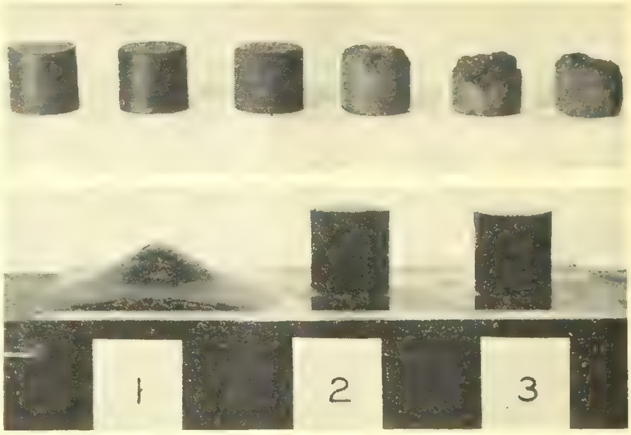

Figure 18.—Upper; Soil Samples Containing Water-Gas Tar in Various Amounts, Photographed After Immersion in Water for a Period of Two Weeks. Lower; The Effect of Portland Cement and Bituminous Material on the Slaking Properties of a Silt Soil.

tar in appreciable amount and exhibited no signs of disintegration. The third cake from the left contained but a small amount of tar and crumbled to a slight degree along the top edges. The fourth cake from the left contained but a slight trace of tar and crumbled in appreciable amount near the top. The two cakes on the right contained no visible trace of tar and disintegrated to a marked extent.

Figure 18 also shows the effect of portland cement and bituminous material on a silt soil (*14*). Sample 1 was untreated and slaked completely when immersed in water for a few minutes. Sample 2 was treated with portland cement, and sample 3 with bituminous material. Both samples 2 and 3 showed no evidence of slaking during periods of immersion lasting several months.

Efforts to stabilize fine-grained soils by admixtures of lime and cement materials were made in Iowa and South Dakota as early as 1924 and in Ohio several years later. The results of early work were not particularly promising but they should not be considered as indicating the possibilities of such treatments, because the requirements of thorough distribution of admixture, high degree of compaction, and protective surface treatment now deemed necessary were not recognized in the earlier work.

More recent research on the use of portland cement for stabilizing soil bases was performed in South Carolina by the State highway department. The purpose of this work has been to develop a base material that could be constructed at less cost than that required to provide one of properly graded sand-clay or top soil.

Experimental work in the treatment of soils with bituminous materials has recently been conducted in various parts of the country. Sections of highway have been constructed using different grades of tars, road oils, and bituminous emulsions. Airplane landing fields have also been stabilized with bituminous materials.

The use of the combined sodium-silicate and calcium-chloride treatment has been confined largely to the stabilization of coarse-grained soils supporting buildings and other structures.

VARIOUS METHODS USED IN SOIL ROAD CONSTRUCTION

The following is a general description of the best practice that has been developed to date in the construction of stabilized road surfaces. It should be used only as a general guide and it may be expected that better methods will be developed.

When a highway is built on a new location, a sufficiently wide roadbed or subgrade is first constructed, using available materials. Loose, sandy subgrades should be improved by the addition of soil binder; soft, unstable subgrades should be improved by the addition of granular material. The added material should be thoroughly mixed into the subgrade by harrowing or blading, after which the subgrade is brought to true alinement and grade by blading and rolling. Excess subgrade material that is suitable for use as binder for the wearing course can be bladed to the shoulders of the road and left in windrows during the preparation of the subgrade.

When an existing highway is improved, material is added or taken away to obtain the desired width, grade, and alinement. Soil binder or granular material is added in sufficient amount to obtain a stable mixture, and is thoroughly mixed into the subgrade by harrowing or blading.

There are three methods for obtaining the desired mixture—plant mixing and road mixing, and by using the "cut and try" method.

Plant mixing.—The essential requirements of a plant-mix job are a source of satisfactory binder in close proximity to the supply of coarse aggregate to be used; means for drying and pulverizing the binder; apparatus for measuring the quantities of binder and aggregate to obtain the proper proportions; and equipment for thorough mixing of the combined materials.

An ideal location for a mixing plant such as that shown in the lower picture in figure 19 is near a place where the overburden consists of a clay soil having satisfactory binder properties. This overburden may be stripped and stockpiled in windrows so that it will dry sufficiently to be pulverized under a roller. The clay should then be combined with an aggregate of proper grading in such proportions that the resulting mixture will conform to the specifications. Thorough mixing should be provided by means of a pug mill or rotary-type mixer.

In some plant mixes, bank-run gravel and the existing overburden have been used and the drying and pulverizing steps have been eliminated by passing the combined materials through a rotary screen or over a grill to remove oversize material.

The mixture is hauled to the road, spread, sprinkled, shaped, and rolled. The principal advantage of the plant-mix method is that a more thorough mixing of the binder and aggregate is obtained.

Road mixing.—The necessary equipment for mixing the materials on the road includes tractor-drawn or self-propelled blade graders, scarifiers, harrows, and other apparatus for mixing, moistening, spreading, and compacting the base- and wearing-course materials. Scarifiers may be either of the four-wheel type or of the type attached to the roller. (See fig. 20A.)

Disk harrows should be such that unintended cutting into the subgrade can be avoided. Either the spring or spike-tooth harrows that assure positive control of the depth to which the teeth will penetrate are satisfactory. For mixing and shaping, power-drawn blade graders with a wheel base of not less than 16 feet are satisfactory. (See fig. 20B.) Multiple-blade maintainers may be of the truck-suspended or drawn type.

The surfaces of existing roads should be scarified deep enough to eliminate all irregularities of the surface and to permit reshaping to grade. After the loosened material is shaped to grade, the surface should be scarified to a uniform depth. New material, if required, should be spread on the loosened surface in amount sufficient to furnish a compacted layer of approximately 3 inches. If greater surface thickness is desired, additional layers should be constructed.

The material is mixed until it is uniform throughout by means of harrowing and turning with blade graders. The water required to obtain the proper moisture content in the wearing course is supplied in the following manner. After the mixture of binder and gravel is bladed onto the shoulders of the road, the base is moistened uniformly using a suitable sprinkler, and approximately one-fourth of the material from the windrows is bladed immediately onto the moistened base. The newly distributed road material is then similarly moistened and covered as before with one-fourth of the original windrowed mixture. These operations are repeated until the last layer of dry mixture has been placed.

Before moistening this top surface material, the road is shaped and compacted. Because properly graded mixtures contain enough granular material to provide for mechanical interlocking, a load applied at the top of an unconsolidated or partially consolidated layer is readily transmitted vertically and causes consolidation throughout the thickness of the layer. Consequently any means of applying adequate load whether it be a flat-wheeled roller, a crawler-type tractor, truck graders, other trucks, or vehicular traffic, will assist in the compaction of graded mixtures. After shaping and initial compacting are completed the surface is thoroughly dampened and again compacted.

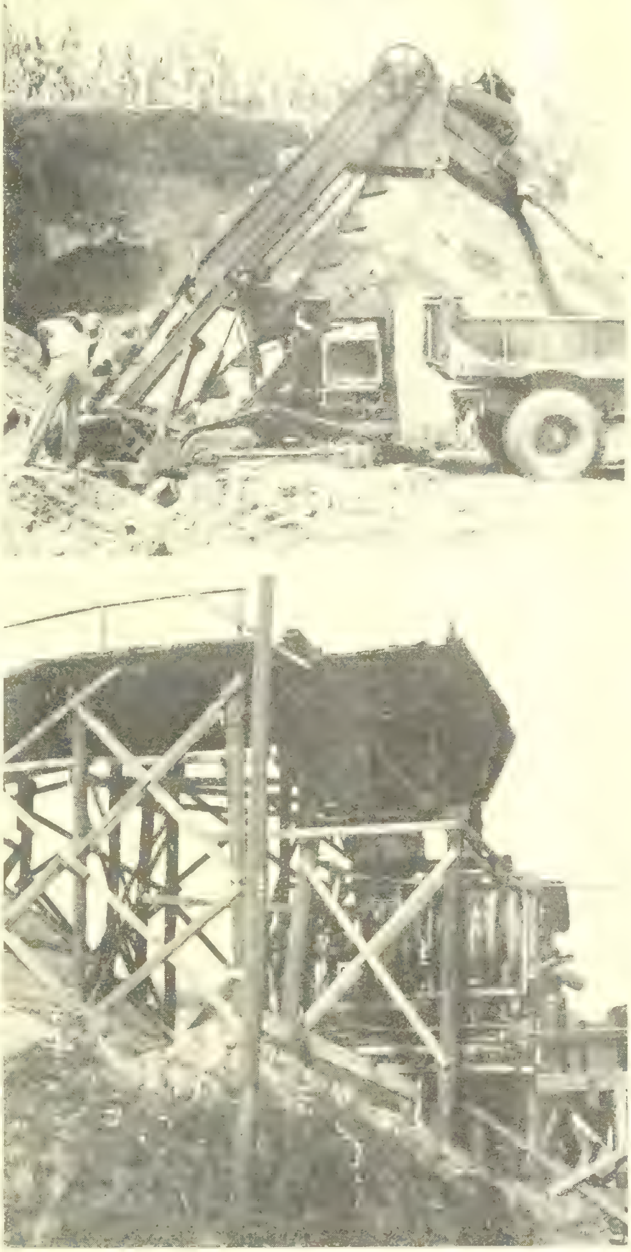

Figure 19.—Mixing Equipment Used in Stabilized Soil Road Construction. Upper; The Clay Overburden and Gravel are Mixed in Proper Proportions and Loaded Directly into Trucks. Lower; This Plant was Used to Mix Clay Overburden and Graded Crushed Stone from an Adjacent Quarry.

During the period of final compaction the loose material should be kept distributed over the road surface by means of a road drag or blade grader. The amount of crown maintained by blading operations should be sufficient to provide for the rapid run-off of storm water in order to prevent the formation of pools of water on the road surface. Pitting of the surface is an indication that the crown is too slight.

"CUT AND TRY" METHOD USEFUL UNDER CERTAIN CONDITIONS

In the construction of roads on farms, and from farms to adjoining local roads, or under similar con-

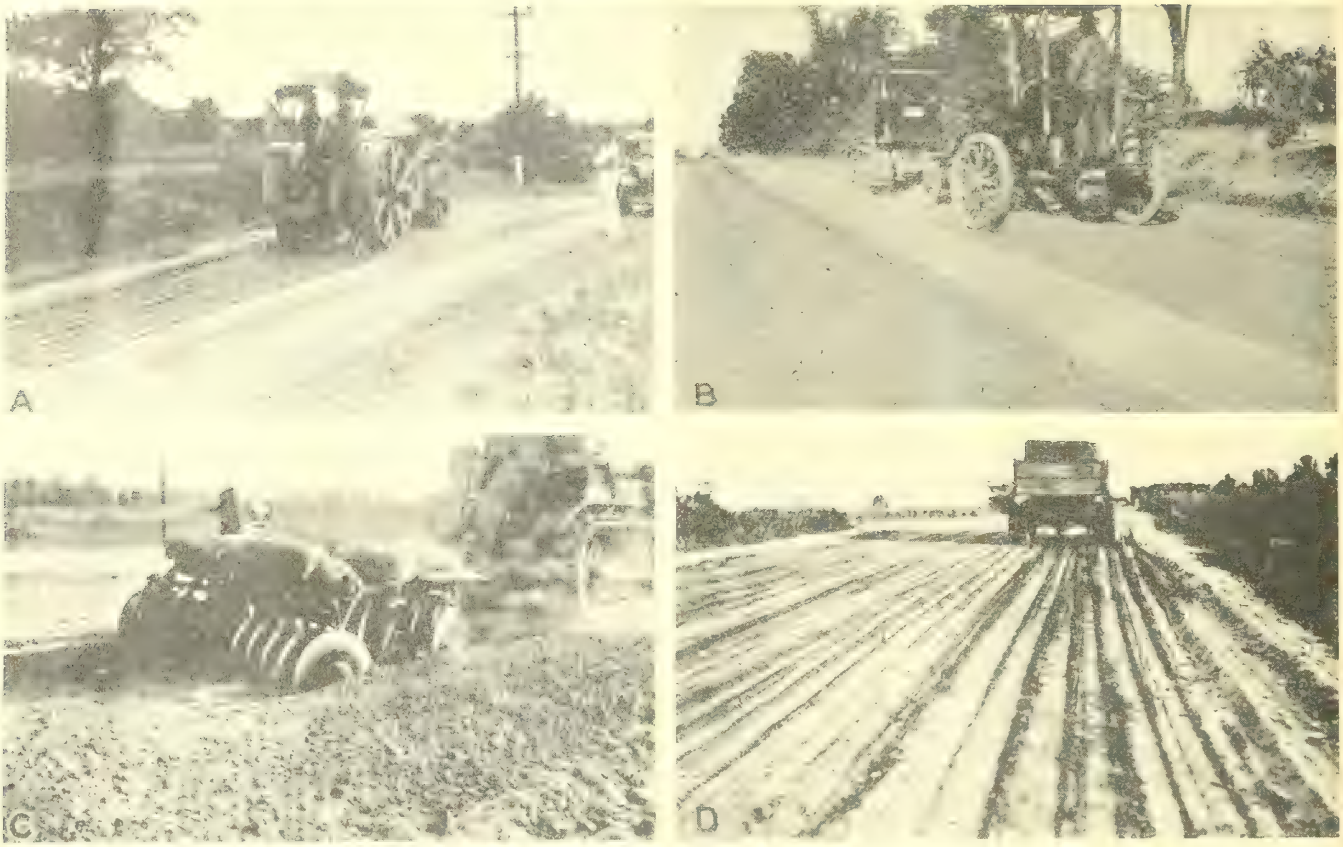

Figure 20.—Steps in the Construction of Stabilized Soil Roads. A, Scarifying a Gravel Road; the Loosened Aggregate Will Be Used in the Stabilized Mixture. B, Mixing the Dry Materials with a Blade Grader. C, Mixing the Dry Materials for a Cement-Treated Road with a Disk Harrow. D, Compacting the Wet Materials on a Cement-Treated Road.

ditions where facilities for making precise determinations of grading of materials may not be available, the proper grading to furnish stability may be determined by "cut and try" methods.

The "cut and try" method has been used extensively in the construction of traffic-bound roads. Essentially, it consists of adding granular materials to surfaces that become excessively muddy during wet weather and adding clay soil to loose, sandy, and gravelly materials. The amount of either material added may vary considerably for different conditions and must be determined by trial. Usually, granular material is added in layers several inches thick. If, after this material is worked into the soil, a muddy condition persists in rainy weather, more granular material is added. If too much granular material is added the surface becomes loose and will not compact properly. Care should be taken to avoid adding an excess of clay to granular material, as when granular material is added to a clay surface the granular material may make up as much as 80 percent of the total surface course, but a very small amount of clay, possibly only 15 percent, will be required to stabilize loose sands and gravels. An effort should be made to powder the clay as finely as possible.

A sample of well-graded sand and binder soil may assist in the selection of soil mixtures that have the desired properties.

If a sample of well-graded material is wetted and squeezed in the hand, the following characteristics will be noted: (*a*) The soil is extremely gritty; (*b*) it can be formed into definite shapes that retain their forms even when dried; (*c*) if the clay alone adheres to the hands, it will only be enough to discolor them slightly; (*d*) if more than enough soil to discolor the hands adheres to them, it will consist of both sand and clay instead of clay alone; and (*e*) when the wetted sample is patted in the palm of the hand it will compact into a dense cake that cannot be penetrated readily with a blunt stick the size of a lead pencil. These characteristics indicate well-graded material. The grittiness of the sample indicates the presence of sufficient granular material. Development of some strength on drying indicates a sufficient amount of binder soil. Resistance to the penetration of the pencil or stick, even when the sample is thoroughly wetted, indicates a desirable interlocking of the grains and the presence of a sufficient amount of capillary force.

Too much sand would cause the sample to fall apart when dried. Too much clay would leave the hand muddy after the wet sample was squeezed and would cause the wet sample after being patted to offer little resistance to the penetration of the stick.

ADMIXTURES APPLIED BY SIMPLE METHODS

In plant mixing, calcium chloride is generally added to the mixture at the plant. In road mixing calcium chloride is applied in the following manner:

After the new and old soil materials have been spread over the prepared base in sufficient thickness, they should be covered uniformly with flake calcium chloride in the amount of ½ pound per square yard per inch of thickness, with a maximum of 2 pounds per square yard. The spreaders should be capable of spreading the chemical uniformly and in the desired quantities. The calcium chloride is then thoroughly worked into the soil by harrowing and blading until the surfacing material is uniform throughout. Sprinkling and shaping into a finished surface is then accomplished in the same manner as in the case of the untreated roads already described.

In construction using the cut-and-try method, calcium chloride may be applied to the road surface after its condition indicates that a proper gradation of materials has been obtained. The chemical may be applied by mechanical spreaders as on road mix jobs or it can be conveniently spread by means of a hand shovel.

Calcium chloride should not be applied during periods of cold, wet weather. The most favorable time for a surface application of calcium chloride is during the drying period just following a rain, after the surface has been bladed to proper smoothness. The moisture in the road at that time hastens solution and penetration. In the absence of rain, application in the early hours of the day, when the air has high relative humidity, is very desirable. Calcium chloride applied just prior to a rain will probably be washed off the road and consequently afford little or no benefit. When blading of the calcium-chloride treated road is required, it should be done after rains or commenced near the end of a rain. At other times the surfaces may be too hard. For patching holes an admixture of 100 to 150 pounds of calcium chloride per cubic yard of graded soil is recommended.

Need for extensive patching during dry weather can be minimized or eliminated by periodic maintenance with light applications of calcium chloride during the season.

In the use of calcium chloride as a dust palliative, it has long been known that this material remained effective for much longer periods in gravel having a clay binder than in gravel having a sandy filler. It has also been apparent that the presence of loose gravel tended to shorten the useful life of a treatment. The intermittent movement of such loose gravel by traffic and maintenance operations exposes new surfaces to the air and promotes evaporation.

Sodium chloride may be added at the plant for a plant mix or to the mixture on the road for a road mix. Rock salt has been used most generally, but any commercial type of pure salt or salt brine is satisfactory. The coarser grades of rock salt are well adapted for stabilization, as they remain free-flowing and can be more uniformly spread than the finer gradations, which will absorb moisture and cake when stockpiled along the road. The salt should contain not less than 98 percent of pure sodium chloride.

When sodium chloride is applied in the form of brine any of the gradations of the salt may be used, since the condition of the salt before it is dissolved is unimportant. The stabilized mixture will remain plastic longer if all of the salt has been dissolved, thus permitting rolling and compacting to be continued over a long period of time with the possibility of attaining greater ultimate compaction. There should be enough water to moisten the soil somewhat above the plastic limit.

In Indiana it was found that from ¾ to 1¼ gallons of water per square yard per inch of thickness were needed to moisten the mixture satisfactorily. This was slightly more than 20 percent by weight of the soil fines. If there is overwetting of the surface mixture, there is danger of vehicles cutting through the surface course and mixing it into the subgrade.

Water is usually added by means of pressure distributors, sprinkler wagons, or gravity tank trucks. It is preferable to make several trips over the section under construction, sprinkling lightly on each trip. This gives the moisture a chance to penetrate sufficiently and does not result in a sloppy condition on the surface. The amount of salt used varies somewhat in the different States. The usual amount is about 2 pounds per square yard per 3-inch thickness of road constructed. Indiana requires ¾ pound per square yard per inch thickness, regardless of thickness of the road constructed.

During prolonged dry periods the fine aggregate may wear off of a sodium-chloride treated surface, leaving the larger aggregate particles protruding. This condition can be corrected by covering the surface to a depth of about ½ inch with properly proportioned soil mixtures containing about 100 pounds of sodium chloride per cubic yard. When damp the mixture makes a satisfactory bond with the worn surface without scarification.

If, during periods of rainfall, the top eighth or quarter of an inch of stabilized roads becomes plastic, crushed aggregate should be added to the surface in amounts of about 50 to 70 tons per mile. This aggregate should have a maximum size of about ½ inch and should be free from dust and sand. The material should be spread over the surface and kept uniformly distributed as long as the surface is wet. The thin surface layer of fines acts as a cementing agent for the coarse aggregate that has been added. This results in a satisfactory driving surface, adds some additional thickness to the road, fills up any depressions that may have developed, and reduces the tendency for pot holes to form.

STABILIZATION OF FINE-GRAINED AND POORLY GRADED SOILS REQUIRES SPECIAL CARE

Practice in the stabilization of fine-grained soils differs in several respects from the procedures used in the construction of roads with well-graded mixtures. Care must be taken to provide for the optimum moisture contents when only water or electrolytes are used as admixtures, because it is particularly important to obtain the maximum density.

Special means are needed to insure uniform distribution of all materials when cement and bituminous materials are used as binders and when crushed rock, slag, etc., are used as primers or neutralizers. This is because of the much greater surface area to be covered in the fine-grained materials. A cubic foot of sand composed of grains 1 millimeter in diameter has a total interstitial surface area of about 1,000 square feet; that of the same volume of silt composed of grains 0.02 millimeter in diameter is about 50,000 square feet, or more than 1 acre, and that of a cubic foot of material composed of grains only 0.001 millimeter in diameter is about 1,000,000 square feet, or about 23 acres. It has been estimated that a cubic foot of ordinary loam soil has a surface area of about 1 acre, and that of an equal amount of fine clay soils is about 4 acres.

Compacting equipment designed to produce a predetermined degree of densification during construction must be used, instead of depending upon traffic to produce the maximum density afterward, although traffic may cause a slight increase in density under certain conditions. When coarse particles are absent, or are present in such amounts that they are surrounded by the cohesive, fine-grained particles, the effect of a load applied to a layer of such material is to consolidate that portion immediately beneath the load without adequately compacting the particles in the lower part of the layer. Consequently, rolling fine-grained soils with a flat-wheel roller may produce undesirable stratification and insufficient consolidation. The prongs of a sheep's-foot or tamping-type roller, or equipment that produces similar effect, are required to penetrate the unconsolidated material and compact the layer from the bottom upward in order for the layer to be consolidated uniformly throughout its thickness without stratification.

When only water or electrolytes are used as admixtures, it is especially important that the soils should be compacted by means of a sheep's-foot roller, or apparatus giving similar effect, at optimum moisture content and to a density indicated by the Proctor tests. Construction with admixtures of portland cement and bituminous materials does not require such extreme care in order to obtain satisfactory results.

Bituminous surface treatments are required to provide fine-grained soil roads with the resistance to abrasion and softening under traffic furnished by the coarse aggregate in graded soil mixtures.

Stabilization with cement and bituminous materials.—The construction methods used on experimental work in South Carolina (*23*) were substantially as follows: The cement was spread on top of the pulverized soil at the rate of about one sack per linear foot of roadway 18 feet wide. The dry soil and cement were mixed with disk harrows supplemented by a disk plow or road machine (fig. 20c). Water was then added at the rate of about 8 gallons per linear foot and compaction was accomplished by means of loaded trucks with dual tires (fig. 20d). The surface was finished with a blade grader after compaction. A bituminous surface treatment was applied subsequently to provide against surface abrasion.

All of the experimental sections are reported to be in good condition at the present time and no disintegration has been observed.

Construction with bituminous emulsion is illustrated by a project in Solano County, Calif., described by C. L. McKesson (*21*). Laboratory studies indicated that the natural adobe clay soil could be stabilized to a depth of 3 inches with about 3 gallons of 55 percent emulsified asphalt. By adding 2 parts of quarry waste to 1 part of the clay, stabilization was accomplished with 1 gallon of emulsion per square yard, a saving after paying for the quarry waste of about 5 cents per square yard. The construction methods were as follows:

The quarry waste was uniformly spread on the clay subgrade to a loose depth of 1¼ inches and scarified into the natural clay. The loose mixture was 4½ inches thick. The clay and quarry waste were well mixed by harrowing.

The soil mixture was then dampened with about 2 gallons per square yard of water and the water was mixed in by harrowing.

The emulsified asphalt was then applied, after dilution with four parts of water (fig. 21).

The diluted emulsified asphalt was applied in six applications. After the first application of emulsion the mixture was harrowed and then the top inch of the mixture was bladed to the sides. This was repeated after the next two applications of emulsion. The soil mixture was then in two windrows on the sides, and was distributed back over the road in three spreads and dilute emulsion was applied to each.

To obtain thorough mixing, the soil-emulsion mixture was again bladed into windrows and then brought back in thin layers and finally shaped to the required cross section.

The tractor used to pull the mixing equipment had by this time fairly well compacted the road surface. The lower picture in figure 21 illustrates the compacting operation as performed on a similar job.

One gallon of emulsion and 6.2 gallons of water were used per square yard, including the water used in the preliminary dampening operation.

This completed the soil stabilization and there remained only the surface treating.

The surface was then given an application of approximately ¼ gallon per square yard of the emulsion, diluted with an equal part of water and immediately covered with 40 pounds per square yard of ½ to ¼ inch crushed stone.

The surface of the road was then rolled. The crushed stone was embedded in the stabilized soil mixture. A final application of 0.64 gallon per square yard of undiluted emulsified asphalt was then spread and immediately followed with 15 pounds per square yard of ¼ inch to no. 10 sieve crushed stone, followed by brooming and rolling.

The road was not closed to traffic at any time during the construction of this project. Upon completion the road resembled bituminous macadam in appearance. This road came through the rainy season in perfect condition although the subgrade was saturated and plastic.

STABILIZATION PROCEDURES NOT STANDARDIZED

It should be kept in mind that other procedures using portland cement and bituminous materials in soil stabilization are in a state of development and those just described are given as examples. Numerous experiments are being carried on, some involving use of the optimum moisture content as disclosed by the Proctor tests and compaction with sheep's-foot rollers, while in others traffic is largely depended upon for compaction.

An experimental stabilized road in Jackson County, Mo., (*10*), was compacted by traffic. Asphaltic materials used as stabilizers were introduced at desired depths below the surface of the loose road mix by means of a specially constructed "sub-oiler" illustrated in figure 22. It is essentially a tooth scarifier having an oil line attached to the back of each tooth and running nearly to its points.

The theory back of this procedure has been that as moisture evaporates from the overlying soil the moisture films will be replaced by liquid asphalt. The report states that roads consisting of heavy, sticky clay or gumbo types of soil are water resistant after treatment and unaffected by rains.

Another method for incorporating the asphalt into the soil was tried in Missouri during 1935 (*26*). The clay surface was scarified, and the loosened material

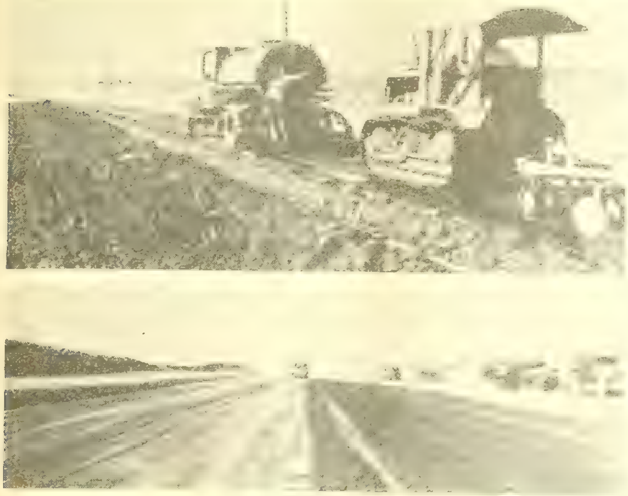

Figure 21.—Upper; Applying Bituminous Emulsion and Mixing with a Disk Harrow. Lower; Rolling a Base Course Stabilized with Bituminous Emulsion.

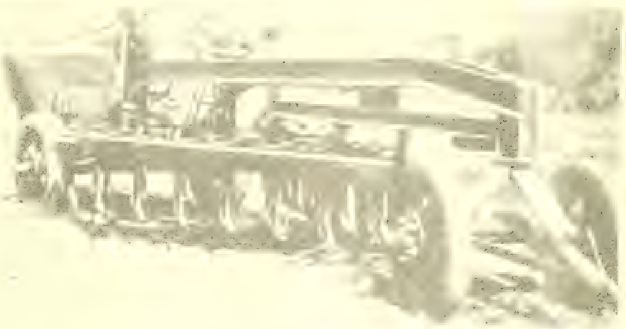

Figure 22.—Sub-Oiler for Applying Bituminous Material in Soil Stabilization.

windrowed and mixed with the desired percentage of bituminous material by means of a traveling mixing plant. Prior to scarifying, varying quantities of aggregate were added to test the efficiency of additional coarse material in case too great a degree of plasticity was induced, and also to check the relative efficiency from the viewpoint of economical construction.

About 35 gallons of water per cubic yard of mixed material were added to facilitate mixing in the pug mixer. The sections that had time to dry prior to freezing carried traffic with little or no signs of distress, although there was some evidence of a sponginess or rubbery action indicating that future additional consolidation would and should take place.

The use of tar in soil road stabilization has been described (*37*). The tar used consisted of two grades. Grade 1 tar had a specific viscosity of 4 to 8 (Engler) at 40° C., and grade 2 tar had a specific viscosity of 26 to 36 (Engler) at 50° C.

After the road was graded and shaped the soil was pulverized over a width of 22 feet. Grade 1 tar was added to the loosened soil, thoroughly mixed in, and the mixture windrowed. Grade 2 tar was added later and the mixture spread and compacted by traffic.

The moisture content of the soil varied from 2.9 percent to 7.5 percent at the time the tar was added. About 1.4 gallons of grade 1 tar per square yard and about 2 gallons of grade 2 tar per square yard were required.

A tack coat of about 0.26 gallon of grade 2 tar per square yard, covered with sand, was applied to the surface to prevent dusting under traffic. A bituminous wearing course was to be applied later.

Soon after this section of stabilized road was constructed, the following observations were noted.

1. A very light-viscosity tar mixed with soil results in a mixture that is very resistant to water.

2. Unless a tar mixture is covered by a seal coat very soon after it is mixed a portion of the tar will apparently disappear.

3. Small lumps of clay soil do not seem to cause any trouble if the lumps are surrounded by material impervious to water and protected from traffic.

Determination of the moisture content and degree of densification of the material being placed by means of the tests suggested by Proctor are important in many types of soil stabilization. The moisture contents are determined by packing the wet soil in the Proctor cylinder, weighing, measuring the resistance to penetration, and comparing these values with the laboratory curves for wet weight and resistance to penetration for the particular sample. Checks on these values may be made by oven-drying small samples to determinle the moisture contents more accurately. If the soils are found to be below the optimum moisture content they are sprinkled with water, and if found to be above the optimum they are spread in thinner layers and allowed to dry either before rolling or during longer rolling periods.

The extent of consolidation is determined by measuring the resistance to penetration of the soil layer in place, and comparing the values with the readings obtained when the same soil was compacted in the standard manner in the cylinder. If the plasticity needle readings for the soil layer are less than those for the soil in the cylinder, more rolling will be required. This test is not used as extensively as the dry weight test because the presence of gravel in the material interferes with the needle and gives distorted values.

Check tests on the degree of consolidation are made in the following manner. Approximately 15 pounds of the compacted soil are removed from the layer with a post-hole auger and weighed. The same soil is then packed in the Proctor cylinder, weighed, and the density and moisture content computed as in the regular tests. The hole from which the material has been taken is filled with sand of a known loose weight per cubic foot and the volume thus measured. The wet and dry densities of the compacted material are determined from the weight, moisture content, and volume. A comparison of the densities of the wet soil in place and the same soil compacted in the cylinder in the standard manner immediately indicates whether more rolling is required or whether less rolling will suffice.

SUMMARY

Substantial progress has been made in obtaining a better understanding of the basic theories of soil stabilization and the manner of applying them in the design and construction of stabilized roads.

Data on the effect of temperature, degree of compaction, and grading, and data on the use of admixtures of electrolytes, fillers, neutralizers, and insoluble binders indicate that:

1. The outcome may be unsatisfactory when clay soils are compacted to a given extent without regard to moisture content, or when compacted with a given moisture content without regard to the type or extent of compaction.

2. Soils compacted to maximum density at low temperatures may soften due solely to the water liberated from the adsorbed films by a rise in temperature.

3. For equal amounts of compacting, greater densities can be attained at high temperatures. To obtain the same densities more work of compaction will be required at low temperatures.

4. For equal work of compaction, well-graded mixtures become the densest.

5. Admixtures of granular aggregate may effect a three-fold change: (*a*) Improve the quality of the clay due to electrochemical phenomena, (*b*) reduce the surface area per unit volume, and (*c*) increase the internal friction of the mixture. The low silica types and the alkaline clays are likely to make the best binders. Other clays may be improved by admixtures of slag, crushed stone, and gravel.

6. In the construction of fine-grained base courses it is felt that the use of the insoluble binders such as portland cement and bituminous materials is likely to prove more satisfactory than attempts to stabilize with moisture films alone.

7. Mixtures of acidic and basic rocks show a higher cementing value than either alone. It seems possible by selecting and blending certain road stones or by treating the road with a suitable chemical salt or base to increase greatly the natural bond at the road surface.

8. It is especially essential that mixtures having the proper characteristics be used in the construction of base courses. They should be used also in surface courses, but trouble developing here due to the use of unbalanced combinations of materials may be corrected as a maintenance measure. A similar trouble in base courses cannot be so easily corrected and consequently may result in expensive failure of the entire road structure.

That mixtures with clay binders have served satisfactorily as road surfaces is no assurance that they will not fail completely under the almost continuous moist conditions produced when evaporation is stopped by coverings of impervious wearing courses. Without a thorough knowledge of the swelling properties of soil binders, the risk of failure that attends the practice of constructing impervious wearing-courses on soil-bound mixtures that have become highly stable under traffic cannot be overemphasized.

9. It seems feasible to use admixtures of electrolytes and fillers to obtain the desired densities when compacting the more porous soils, and to decrease the amount of compacting required to consolidate soils of the better grades. When in the semisolid state, soils require greater amounts of compacting than when in the plastic state. As a practical consideration, therefore, it seems desirable to consolidate fine-grained soils in the plastic state (where the films act as lubricants) but near enough to the plastic limit so that evaporation during compacting will be sufficient to leave the finally compacted soil in the semisolid state (where the films act as adhesives). Soils with optimum moisture contents slightly below the plastic limit and with initial moisture contents for mixing and compacting slightly above seem to provide a favorable balance between lubricating and adhesive properties.

10. The success of road construction in the low-cost field demands that special attention be directed toward simple operations and the use of local materials. Nevertheless, the importation of commercial aggregates and fines to improve the quality of soils of poorer grades may be advisable in the interests of ultimate economy of construction and maintenance and of type of service rendered.

More than 2 million miles of our rural roads are unimproved. Developments in the field of soil stabilization will make possible the improvement of greater mileages of these roads with the funds available.

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STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936 FUNDS

AS OF APRIL 30, 1936

STATE	Apportionment	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			Balance of funds available for new projects
		Estimated total cost	Federal aid	Miles	Estimated total cost	Federal aid	Miles	Estimated total cost	Federal aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 493,754	$ 369,374	39.9	$ 1,480,609	$ 1,218,757	61.6	$ 35,566	$ 28,641		164,575
Arkansas	2,142,723										2,142,723
California	4,756,959	378,250	194,832	7.5	4,997,418	2,603,759	83.3	1,996,526	1,149,995	60.5	808,373
Colorado	2,358,811	399,025	222,933	21.6	2,375,115	1,297,676	72.1				838,202
Connecticut	791,253				364,334	176,660	4.8	897,493	422,404	10.2	192,189
Delaware	609,375				264,927	132,464	32.7	184,689	92,344	4.1	384,567
Florida	1,655,723				814,632	407,316	27.5	218,968	109,484	8.7	1,138,923
Georgia	3,198,221				978,439	489,220	74.5	1,491,550	745,775	80.5	1,963,226
Idaho	1,531,162	292,520	164,327	44.6	1,694,511	952,062	127.6	64,242	38,442	6.0	376,331
Illinois	5,160,696				5,690,571	2,842,931	92.1	2,762,116	1,344,057	35.8	973,708
Indiana	3,087,613	247,908	123,949	6.9	5,086,534	2,543,267	173.5	557,038	278,519	21.4	141,878
Iowa	3,231,718	224,762	105,460	57.5	4,373,949	2,299,215	217.2	1,488,632	743,973	130.6	83,070
Kansas	3,317,054	162,776	81,388	145.1	2,254,336	1,127,168	157.1	1,829,149	914,574	229.4	1,193,924
Kentucky	2,304,143	604,406	302,203	33.4	1,554,765	762,800	102.3	1,450,355	690,896	37.7	548,244
Louisiana	1,776,939	190,485	95,242	4.9	1,832,314	916,157	60.5	878,383	439,192	29.8	326,348
Maine	1,090,167	113,605	56,803	2.1	1,598,729	799,364	51.5	191,524	95,762	4.1	138,238
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877				333,935	166,968	3.1				1,574,909
Michigan	3,837,292	1,025,185	512,595	33.2	4,213,918	2,104,234	152.0	1,925,250	962,625	81.8	257,838
Minnesota	3,423,306	350,412	145,842	12.2	3,505,244	1,524,512	253.5	2,792,640	1,384,680	191.7	368,272
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,126,860	562,609	221.1	3,160,360	1,580,179	126.4	1,494,627	747,314	62.0	910,554
Montana	2,560,449	661,394	370,182	141.9	2,786,348	1,560,076	186.3	1,076,228	602,580	97.6	27,611
Nebraska	2,581,663	1,104,139	552,023	66.5	694,306	347,165	73.4	150,049	75,025	16.3	1,607,450
Nevada	1,595,501	232,553	200,035	74.0	905,998	784,321	93.0	171,338	148,328	28.3	462,817
New Hampshire	609,375				760,312	374,109	22.2	141,629	70,736	1.9	164,530
New Jersey	1,675,751	50,782	25,391	.3	2,067,366	1,033,683	29.7	1,321,388	574,163	10.4	42,514
New Mexico	1,999,299	159,058	96,739	18.4	2,044,483	1,243,454	147.0	624,267	379,679	18.5	279,427
New York	6,150,106				9,226,855	4,559,450	165.6	2,031,775	1,011,862	30.8	578,794
North Carolina	2,938,657	87,050	43,525	15.2	1,310,435	652,752	212.4	1,790,335	876,800	187.6	1,365,580
North Dakota	1,960,162							187,005	101,941	.1	1,858,221
Ohio	4,565,435				2,785,282	1,392,342	40.3	3,206,410	1,418,115	38.0	1,754,978
Oklahoma	2,947,521	52,070	27,363	2.1	1,674,653	877,775	56.0	769,596	404,422	21.3	1,637,961
Oregon	2,044,633	191,986	116,264	4.1	2,672,073	1,628,599	91.3	457,854	266,128	14.0	33,642
Pennsylvania	5,348,062	60,985	30,492	1.6	5,229,340	2,614,670	77.2	2,412,428	1,205,369	34.1	1,497,531
Rhode Island	609,375										609,375
South Carolina	1,692,896				50,787	25,393		34,891	15,701	8.7	1,651,802
South Dakota	2,036,775				516,850	283,389	35.2	644,924	384,877	95.9	1,368,509
Tennessee	2,638,159	126,573	63,286	5.1	1,372,457	686,229	56.9	111,392	55,696	4.1	1,832,948
Texas	7,777,504	2,360,023	1,178,103	137.0	6,276,939	3,133,066	354.6	3,520,848	1,718,407	176.9	1,747,928
Utah	1,410,752	269,089	189,239	17.0	1,243,850	873,988	85.9	341,101	244,015	16.5	103,510
Vermont	609,375	22,052	10,786	2.9	1,136,311	568,156	52.2	39,201	19,600	4.2	10,833
Virginia	2,278,475				1,737,000	868,500	69.8	937,550	493,775	28.1	916,201
Washington	1,949,957	637,516	335,555	20.5	2,153,296	1,135,649	62.8	307,946	162,000	8.2	316,752
West Virginia	1,356,793	87,161	43,581	3.0	754,175	377,087	36.5	340,482	170,229	9.1	765,896
Wisconsin	3,045,557	511,344	255,672	18.9	1,692,693	843,754	75.5	1,235,120	667,560	48.7	1,278,571
Wyoming	1,559,444	627,026	385,738	88.9	1,855,155	1,127,460	185.7	46,782	23,391		22,855
District of Columbia											
Hawaii	609,375				223,629	113,760	2.5	38,429	17,787	1.0	477,828
TOTALS	121,875,000	12,813,349	6,862,091	1,253.4	97,387,273	50,948,676	4,092.4	42,385,961	21,297,363	1,877.6	42,766,870

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF APRIL 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Work Program Funds	Miles	Estimated Total Cost	Work Program Funds	Miles	Estimated Total Cost	Work Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,073,743	$ 3,073,743	97.5	$ 560,971	$ 560,971	13.3	$ 516,401
Arizona	2,569,841	$ 427,711	$ 424,474	34.7	1,572,917	1,356,156	102.3	789,729	399,819	47.0	389,392
Arkansas	3,352,061	45,829	45,829	1.6	1,919,177	1,916,407	152.7	1,074,770	1,061,564	154.6	328,262
California	7,747,928	83,325	79,100	16.2	5,580,393	5,385,993	200.7	129,479	123,037	1.2	2,159,798
Colorado	3,395,263	315,119	315,119	23.6	1,371,127	1,370,736	60.5	146,039	146,039	3.3	1,563,369
Connecticut	1,418,709				220,811	202,552		119,852	115,783	.2	1,100,374
Delaware	900,310				412,363	412,362	34.6	124,520	124,520	24.2	363,428
Florida	2,597,144				1,556,380	1,538,508	60.3	636,930	636,930	16.3	421,706
Georgia	4,988,967				433,342	433,342	29.0	303,348	303,348	19.3	4,252,276
Idaho	2,222,747				1,356,972	1,347,258	106.2	265,159	246,255	24.4	629,233
Illinois	8,694,009	9,995	9,995	.2	5,599,205	5,599,205	274.1	1,965,513	1,965,513	170.3	1,119,196
Indiana	4,941,255				3,354,345	3,354,345	173.7	1,416,736	1,416,736	58.8	170,174
Iowa	4,931,664	15,034	14,100	6.6	1,340,712	1,340,115	141.9	1,178,529	1,120,180	186.8	2,011,269
Kansas	4,994,975	34,551	34,551	20.4	2,541,804	2,541,804	[illegible]	1,836,266	1,836,266	123.3	522,354
Kentucky	[illegible]	9,896	9,836	1.7	1,492,649	1,492,649	[illegible]	1,318,683	1,312,221	108.5	911,505
Louisiana	2,890,429				594,067	472,801	26.6	1,172,919	1,137,215	124.9	[illegible]
Maine	1,676,799				778,761	778,497	35.9	806,057	805,774	33.4	92,528
Maryland	1,750,738				38,893	38,893	1.9	481,161	440,549	23.5	1,271,296
Massachusetts	3,262,885				117,754	117,754	1.1				3,145,131
Michigan	6,301,414	449,100	449,100	25.4	5,273,771	5,213,741	237.0	412,000	412,000	17.7	226,573
Minnesota	5,277,145	175,517	175,517	46.6	1,849,253	1,734,039	159.2	2,678,542	2,231,496	585.1	1,136,094
Mississippi	3,457,552				2,034,717	2,031,623	113.3	1,110,092	1,110,092	94.6	315,337
Missouri	6,012,652	206,655	206,655	110.8	2,840,693	2,830,657	466.9	1,941,992	1,919,891	192.0	1,035,448
Montana	3,676,416	42,612	42,612	2.3	2,888,821	2,888,821	163.5	688,872	688,872	19.8	56,112
Nebraska	3,870,739				1,876,727	1,837,755	192.9	1,056,774	1,056,774	117.6	976,210
Nevada	2,243,074	133,492	133,492	5.1	1,522,471	[illegible]	59.9				586,080
New Hampshire	945,225				335,780	322,876	9.9	190,605	182,292	15.0	440,057
New Jersey	3,129,805				2,014,617	2,014,617	12.9	124,244	124,244	1.2	990,944
New Mexico	2,871,397	242,997	242,997	29.6	1,557,069	1,557,069	101.9	499,299	499,299	79.4	571,031
New York	11,046,377				6,951,408	[illegible]	65.3	3,325,630	3,325,630	34.9	1,187,139
North Carolina	4,720,173	156,966	156,966	21.4	2,175,251	2,092,662	161.7	1,140,416	974,149	[illegible]	[illegible]
North Dakota	2,867,245	156,290	156,290	20.9	319,019	319,019	49.0	[illegible]	[illegible]	[illegible]	[illegible]
Ohio	7,670,815	15,590	15,590	.3	[illegible]	3,094,689	34.0	[illegible]	[illegible]	[illegible]	[illegible]
Oklahoma	4,530,670				[illegible]	[illegible]	4.6	[illegible]	[illegible]	[illegible]	[illegible]
Oregon	3,032,642				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.1	[illegible]
Pennsylvania	9,347,797				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rhode Island	[illegible]	7,184	7,184		[illegible]	[illegible]	13.8	[illegible]	[illegible]	[illegible]	[illegible]
South Carolina	[illegible]	47,193	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
South Dakota	2,976,454	79,686	79,686	50.1	[illegible]	1,721,375	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Tennessee	[illegible]				[illegible]	[illegible]	[illegible]	1,018,647	1,018,647	41.8	[illegible]
Texas	11,939,350	[illegible]	325,521	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Utah	2,047,154	[illegible]	83,784	[illegible]	[illegible]	807,432	31.0	[illegible]	[illegible]	[illegible]	[illegible]
Vermont	[illegible]				[illegible]	447,601	11.0	[illegible]	[illegible]	[illegible]	[illegible]
Virginia	[illegible]	78,821	78,820	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Washington	[illegible]	45,612	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	310,112
West Virginia	2,271,412				1,098,394	[illegible]	44.5	[illegible]	[illegible]	21.1	670,136
Wisconsin	[illegible]	60,250	56,000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,817,805	161.2	292,323
Wyoming	2,219,155				[illegible]	[illegible]	[illegible]	[illegible]	824,550	25.7	[illegible]
District of Columbia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Hawaii	[illegible]				[illegible]	[illegible]	[illegible]				[illegible]
TOTALS	195,000,000	3,683,151	3,622,308	630.8	95,33[illegible],373	93,4[illegible],403	[illegible]	45,596,339	44,894,112	4,007.4	53,063,177

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF APRIL 30, 1936

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		
				Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected by Signals or Otherwise			Eliminated by Separation or Relocation	Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1		$ 2,276,607	$ 2,276,607	24		$ 1,473,819	$ 1,473,819	12	5	$ 275,067
Arizona	1,256,099	47,412	47,412	1		814,319	664,815	8		158,526	158,526	1		385,346
Arkansas	3,574,060					1,057,577	1,053,890	23		1,179,707	1,177,877	22		1,342,294
California	7,486,362					6,018,361	5,774,181	35		385,220	384,122	4		1,328,059
Colorado	2,631,567					1,116,543	1,095,543	18		150,000	150,000	2		1,386,024
Connecticut	1,712,684													1,712,684
Delaware	418,239													418,239
Florida	2,827,883					1,424,039	1,421,728	13		277,906	277,906	2		1,128,248
Georgia	4,895,949					10,581	10,581			344,859	344,859	5		4,540,510
Idaho	1,674,479					852,091	852,091	12						822,388
Illinois	10,307,184					2,295,648	2,295,648	24		3,758,231	3,758,231	32		4,253,305
Indiana	5,111,096					1,996,918	1,996,918	17		1,515,168	1,515,168	5		1,599,010
Iowa	5,600,679	7,303	7,000	1		1,518,955	1,451,000	30		1,220,745	1,164,500	29		2,978,179
Kansas	5,246,258					2,182,819	2,182,819	24		2,773,990	2,773,990	29	1	289,450
Kentucky	3,672,387					957,612	957,612	12		1,804,573	1,279,545	9		1,435,230
Louisiana	3,213,467					48,202	48,202			1,587,938	1,291,651	17		1,873,614
Maine	1,426,861					366,936	366,603	6		295,480	295,480	8		764,779
Maryland	2,061,751					60,000	60,000	1		965,247	942,778	6		1,058,973
Massachusetts	4,210,833					956,239	956,239	6		416,981	416,981	3		2,837,613
Michigan	6,765,197	121,850	121,850	1		4,519,252	4,519,252	36		1,197,200	1,197,200	8		926,895
Minnesota	5,395,441					1,014,882	1,008,832	17		1,194,618	1,194,618	33	8	3,191,991
Mississippi	3,241,475					1,458,857	1,458,857	29		550,817	550,817	13	1	1,231,800
Missouri	6,142,153					1,409,308	1,409,308	11		3,362,170	3,348,902	20		1,383,942
Montana	2,722,327					2,165,879	2,165,879	34		441,025	441,025	3		115,424
Nebraska	3,556,441					1,502,013	1,502,013	46		622,739	622,739	20		1,431,689
Nevada	887,260	40,669	40,669	1		278,735	278,735	6		388,882	388,882	3		178,974
New Hampshire	822,484					207,624	207,624			164,763	164,763	3		450,097
New Jersey	3,983,826					685,340	685,340	4		367,714	367,714	1		2,930,771
New Mexico	1,725,286	136,191	136,191	3		378,820	378,820	5		559,674	547,503	1		662,773
New York	13,577,189					5,859,232	5,597,586	19		2,549,670	2,549,390	5		5,430,213
North Carolina	4,823,958	10,268	10,268			1,132,832	1,132,832	13		475,497	475,497	7		3,205,360
North Dakota	3,207,473					201,184	201,184	5		440,764	440,764	17		2,565,525
Ohio	8,439,897					206,498	206,498	1		828,050	818,050	7		7,415,349
Oklahoma	5,004,711					1,156,729	1,156,729	23		1,263,250	1,258,250	19		2,589,731
Oregon	2,334,204					920,425	919,886	10		1,438,537	1,314,364	9		99,954
Pennsylvania	11,483,613					912,186	880,819	16		2,502,462	2,482,596	21		8,120,198
Rhode Island	699,691					665,505	635,386	4						64,305
South Carolina	3,059,956					958,685	954,232	20		244,723	244,723	5		1,861,001
South Dakota	3,249,086	51,774	51,774	1		531,697	531,697	12		317,092	317,092	9		2,348,523
Tennessee	3,903,979					365,701	365,701	9		248,032	248,032	4	7	3,290,246
Texas	10,855,982	34,420	34,420	2		3,163,714	3,042,357	41		3,246,266	2,845,758	32		4,933,448
Utah	1,230,763					392,410	392,410	4		246,951	234,897	4		603,456
Vermont	729,857					432,826	431,467	5		75,066	75,066	4		223,323
Virginia	3,774,287					550,432	489,103	11		934,089	934,089	30		2,351,095
Washington	3,095,041					1,722,370	1,717,570	19	1	178,600	178,569	4	7	1,198,902
West Virginia	2,677,937									387,238	387,238	2		2,290,699
Wisconsin	5,022,683					2,345,175	2,336,297	20		635,807	635,807	7		2,050,579
Wyoming	1,360,841	55,366	55,365	2		112,085	112,085	1		102,599	102,598	1		1,090,793
District of Columbia	410,804					166,697	166,697	2		253,264	238,616	1		5,491
Hawaii	453,703					296,218	295,333	3						158,370
TOTALS	196,000,000	514,377	514,073	13		59,666,758	58,645,006	679	1	43,525,949	42,010,992	479	29	94,829,929

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF APRIL 30, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Fund	Act of June 18, 1934 1935 Fund	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,351,696	$ 8,174,408	$ 2,819,061	736.4	$ 1,072,225	$ 160,296	$ 911,929	38.5		$ 475,248	3.0	$ 35,429	$ 53,604
Arizona	5,211,960	2,641,935	8,702,843	5,203,929	2,393,040	540.6	289,662		200,270	5.6		28		8,031	48,597
Arkansas	6,748,335	3,428,049	10,430,415	6,563,258	2,900,773	596.9	510,692	63,188	427,196	20.9	$ 21,152	48,548	2.1	100,737	51,531
California	15,607,354	7,932,206	28,200,431	15,590,557	6,639,585	740.2	2,357,572		1,232,628	20.2		820		16,797	59,173
Colorado	6,874,530	3,486,006	11,125,872	6,831,431	3,441,333	636.3	6,817		6,500					43,099	38,172
Connecticut	2,865,740	1,454,868	4,061,007	2,790,583	857,758	69.3	411,623		396,103	3.8		30,000	.9	75,157	171,008
Delaware	1,819,088	923,395	2,643,857	1,819,088	782,660	128.3	32,528		32,528			108,207	1.6		
Florida	5,231,834	2,661,343	8,285,940	5,188,399	1,889,808	288.6	706,372		643,015	20.8		15,955	.8	43,435	112,565
Georgia	10,091,185	5,113,491	11,807,849	9,085,816	2,276,297	674.4	1,549,860	458,333	1,043,504	72.9	257,556	632,826	56.4	289,481	1,160,864
Idaho	4,486,249	2,277,486	6,398,877	4,402,467	1,583,190	489.4	634,861		633,081	12.1	59,759			24,023	61,215
Illinois	17,570,770	8,921,401	21,855,736	15,777,697	5,449,114	612.7	4,932,117	1,685,292	3,144,413	82.1	3,837	27,947		103,944	299,927
Indiana	10,037,843	5,088,963	13,204,271	9,649,030	2,965,002	400.8	2,107,017	196,028	1,876,486	85.1	192,785	210,914	4.6		36,560
Iowa	10,055,660	5,118,361	15,206,714	9,941,506	4,683,028	1,214.2	297,801	114,154	162,100	4.8		245,741	5.0		27,491
Kansas	10,089,604	5,117,675	14,710,316	9,966,308	4,361,660	1,110.8	756,395	39,153	717,242	21.4	68,553	5,140	2.2	15,589	33,633
Kentucky	7,517,359	3,818,311	10,662,755	6,976,085	2,915,989	760.6	1,149,356	463,762	612,448	45.3	29,243	177,476	5.8	48,269	112,398
Louisiana	5,828,591	2,963,932	7,951,371	5,147,521	2,184,476	215.8	1,127,889	608,584	519,305	34.8	53,784	72,999	6.4	18,702	187,151
Maine	3,369,917	1,711,586	5,097,525	3,340,131	1,543,197	191.7	108,297		108,283	1.4				29,786	60,107
Maryland	3,564,527	1,810,058	4,470,983	2,899,421	624,669	114.5	1,035,926	552,686	471,388	33.8	30,000	268,085	11.8	82,420	445,916
Massachusetts	6,597,100	3,350,474	7,112,257	4,601,909	1,883,329	104.3	3,071,060	1,896,850	1,174,210	11.0		2,247		98,341	290,688
Michigan	12,736,227	6,452,568	18,329,024	12,538,746	4,593,335	675.9	2,018,575	163,400	1,797,198	92.1		30,825	.1	34,081	31,211
Minnesota	10,656,569	5,425,551	15,432,903	9,867,696	4,755,179	1,627.3	838,712	646,206	181,274	19.5	11,228	203,936	1.8	131,439	285,162
Mississippi	6,978,675	3,540,227	11,226,383	6,380,117	2,024,248	650.8	1,854,969	495,536	1,267,522	86.0	6,555	206,106	12.2	96,467	42,350
Missouri	12,180,306	6,173,740	15,328,284	10,915,101	3,466,956	1,367.0	4,163,561	1,162,219	2,614,187	84.4		92,597	.4	102,986	
Montana	7,439,748	3,769,734	11,006,131	7,178,165	3,165,014	1,005.3	614,655	159,632	455,023	24.8	57,745	127,440	22.9	44,206	22,257
Nebraska	7,828,961	3,964,364	12,377,511	7,730,371	3,377,810	992.1	814,821	65,535	539,199	43.0		37,959	8.2	33,055	9,396
Nevada	4,545,917	2,302,356	6,753,604	4,484,176	1,988,495	741.9	298,776	26,150	272,626	11.9		5,250		35,591	35,985
New Hampshire	1,909,839	969,462	2,940,544	1,904,950	904,559	77.2	33,288		33,026	.5				4,889	31,877
New Jersey	6,346,039	3,220,879	6,925,209	5,986,387	580,690	76.6	2,644,014	175,941	2,151,139	10.7		303,276	6.6	183,711	185,774
New Mexico	5,792,935	2,941,700	8,506,930	5,624,331	2,667,170	763.5	151,695		151,695	1.1	7,903	29,490	.9	160,702	93,346
New York	22,330,101	11,327,921	37,142,994	21,549,629	9,102,488	799.8	3,176,350	553,400	2,073,999	25.2	156,984	107,442	1.4	70,088	43,992
North Carolina	9,522,293	4,840,941	14,251,872	9,041,120	3,994,645	1,321.2	697,561	122,138	558,528	19.9	180,784	205,439	13.5	178,252	82,329
North Dakota	5,804,448	2,938,967	7,240,549	5,447,197	1,136,441	1,949.5	898,447	169,046	670,806	123.0	29,502	570,011	65.9	158,703	561,709
Ohio	15,484,592	7,865,012	22,635,392	15,286,090	5,642,836	751.2	2,245,826	140,451	1,995,496	43.8	11,000	54,370	.6	47,051	172,310
Oklahoma	9,216,798	4,685,180	13,501,958	9,053,666	3,500,710	794.0	937,178	147,071	788,372	10.6		153,826	1.9	16,060	242,272
Oregon	6,106,896	3,097,814	9,483,883	5,950,972	2,650,162	461.8	434,798	84,475	282,101	6.6		109,293	.8	71,449	56,258
Pennsylvania	18,891,004	9,590,788	27,273,193	17,886,202	8,123,267	981.4	1,791,944	736,539	940,175	77.4	5,126	142,764	1.6	263,136	384,581
Rhode Island	1,998,708	1,014,572	2,982,260	1,998,708	850,541	88.0	139,700		137,982	1.1					26,050
South Carolina	5,459,165	2,770,954	7,235,118	5,216,619	1,819,893	584.8	567,261	32,110	513,192	30.1	49,682	190,289	9.0	160,755	247,580
South Dakota	6,011,479	3,047,643	8,472,324	5,746,663	2,169,531	1,471.0	577,078	21,968	555,110	60.5	85,146	217,548	24.3	157,702	105,455
Tennessee	8,492,619	4,302,991	12,319,297	8,205,810	3,216,289	471.7	1,005,960	285,484	624,075	12.4		321,191	9.0	1,325	141,437
Texas	24,244,024	12,291,253	34,988,590	23,375,505	9,978,559	2,716.2	3,295,610	807,494	2,173,760	70.0		79,831	7.1	61,024	59,103
Utah	4,194,708	2,132,691	7,001,517	4,156,356	1,861,919	584.0	330,104	6,060	268,691	6.9				32,291	2,081
Vermont	1,867,573	948,007	3,033,006	1,863,531	844,822	137.6	109,059	3,922	90,873	2.4		4,750		121	7,562
Virginia	7,416,757	3,765,387	11,187,348	7,148,418	3,103,326	573.0	485,596	112,885	365,260	44.2	55,148	56,488	3.0	100,307	240,312
Washington	6,115,867	3,106,412	8,811,334	6,098,252	2,489,651	292.9	574,946		568,849	10.1		2,387		17,615	45,525
West Virginia	4,474,234	2,280,335	5,523,975	4,312,210	1,005,360	186.7	1,042,371	112,719	875,285	31.7		293,744	4.2	49,305	105,946
Wisconsin	9,724,881	4,941,837	14,746,871	9,697,528	4,261,880	604.3	582,225	7,300	532,483	15.4		110,182		20,053	37,292
Wyoming	4,501,327	2,287,712	6,672,426	4,433,877	2,057,180	1,008.5	236,611	46,705	163,171	28.8		30,154		20,745	37,207
District of Columbia	1,918,469	973,842	2,569,573	1,909,584	659,854	19.4	298,141		262,641	2.9				8,885	51,348
Hawaii	1,871,062	949,778	1,885,014	1,510,686		40.0	1,465,742	351,635	914,171	15.6				8,740	35,607
TOTALS	394,000,000	200,000,000	574,065,732	376,448,207	148,186,779	33,440.4	56,483,644	12,874,347	39,130,538	1,527.1	1,373,472	6,008,769	296.0	3,303,974	6,673,914

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 4 JUNE 1936

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 17, No. 4 June 1936

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

CIRCULAR TRACK TESTS ON LOW-COST BITUMINOUS MIXTURES

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by C A. CARPENTER, Associate Civil Engineer, and J. F. GOODE, Junior Highway Engineer

THE small indoor circular track and the device for applying traffic in making laboratory tests on bituminous surfaces were briefly described in the January 1934 issue of PUBLIC ROADS. This apparatus s being used in the Bureau's laboratory at the Arlington Experiment Farm near Washington to study the various factors that influence the behavior of bituminous road-surfacing mixtures.

The test track, shown in figure 1, is laid in a circular concrete trough 12 feet in mean diameter, 18 inches wide, and 12½ inches in mean depth. The track consists of a base course of gravel, crushed stone, or other suitable material and a wearing course of the bituminous surfacing material to be tested. The surface may be tested dry or the base and also the surface may be flooded or maintained in a moist condition through capillarity by introducing water from a concentric water trough through perforations at the base of the inner curb.

Two automobile wheels, equipped with 20 by 6.00 low-pressure tires and mounted on the ends of a centrally pivoted steel beam, are used for compacting both base and surface and for testing the surface course. The beam is rotated by a motor-driven vertical shaft and operating speeds of 4½, 6, and 9 miles per hour are obtained by the use of a three-step cone pully transmission. The entire weight of the wheel and beam assembly, amounting to approximately 800 pounds per wheel, is imposed on the track.

Distribution of this "traffic" over the entire width of the track during compaction is accomplished by slowly shifting the pivotal point of the beam back and forth through a distance of 18 inches by means of a hand-operated wheel. Although mounted on the rotating beam, this wheel may be operated while the beam is in motion. For compacting, the operating speed is maintained at 4½ miles per hour.

For testing the compacted wearing course, the pivotal point of the beam is set and clamped 2½ inches off center so that the wheels travel in two concentric lanes inches apart. This accelerates the test to some extent by concentrating the traffic and producing a transverse kneading action between the two wheel tracks. The maximum operating speed of 9 miles per hour is maintained during testing.

NE TYPE AND GRADING OF AGGREGATE USED IN ALL MIXTURES

This report describes the use of this apparatus in studying the road-mix or oil-processed gravel type of surfacing widely used in the Western States. Tests were conducted to determine the effect of variations in the quantity and consistency of the bituminous material and the effect of water in the surfacing mixture, in the base, and in both base and surfacing mixture. The density and percentage of voids in the traffic-compacted mixtures, both before and after testing, were determined and specimens of the freshly prepared mixtures were also compacted by various other methods for comparative density studies.

Most of the experimental surfacing mixtures were laid on a sand-clay-gravel base course of the type commonly used in the Western States for road-mix construction. The introduction of water into the base course incident to saturating the surface mixture produced simultaneous failure of both the base and bituminous surface. Therefore, in order to eliminate the effect of base failure, a more rigid type of base course was substituted for the sand-clay-gravel in testing the surfacing mixtures on a wet base.

One type and grading of aggregate was used in all of the surface mixtures discussed in this report. It consisted of 54 percent of crushed Potomac River gravel, 31 percent of Potomac River concrete sand, and 15 percent of local silty soil. The gravel was of good quality and was coarse enough to provide a crushed product of high angularity. It was crushed to pass the 1-inch screen, and 95 percent by weight of the crushed product had two or more fractured faces to the fragment. The filler material was a local silty clay soil that was dried and pulverized to pass the no. 40 sieve. Soil tests on this material gave the following results:

Amount passing the no. 200 sieve, percent	60
Clay content, percent	26
Liquid limit	23
Centrifuge moisture equivalent	20
Plasticity index	7

The aggregate for each mixture was carefully proportioned to conform closely to the grading shown in table 1.

TABLE 1.—*Grading of aggregates used in bituminous mixtures tested on the circular track*

Passing	Retained on—	Percent
	1-inch screen	1.1
1-inch screen	¾-inch screen	5.7
¾-inch screen	½-inch screen	16.3
½-inch screen	¼-inch screen	17.0
¼-inch screen	No. 10 sieve	12.4
No. 10 sieve	No. 20 sieve	10.8
No. 20 sieve	No. 30 sieve	6.0
No. 30 sieve	No. 40 sieve	5.4
No. 40 sieve	No. 50 sieve	4.2
No. 50 sieve	No. 80 sieve	5.4
No. 80 sieve	No. 100 sieve	1.7
No. 100 sieve	No. 200 sieve	3.5
No. 200 sieve		10.5

Five "straight steam-and-fire reduced" asphaltic residual oils were used throughout this series of tests. All were produced from the same crude oil and by the same refiner. The results of laboratory tests on these five materials are given in table 2. Materials A, B, C, and D conformed approximately to the slow-curing, liquid, asphaltic materials of the grades SC–1, SC–2, SC–3, and SC–4, respectively, as defined in the recommended specifications of the Bureau and the Asphalt Institute. Material E was a semisolid asphaltic residue similar to that commonly referred to as 94+ asphaltic road oil. The consistencies of these materials, measured by their float time at 122° F., were 10, 16, 27, 37, and 170, as shown in table 2.

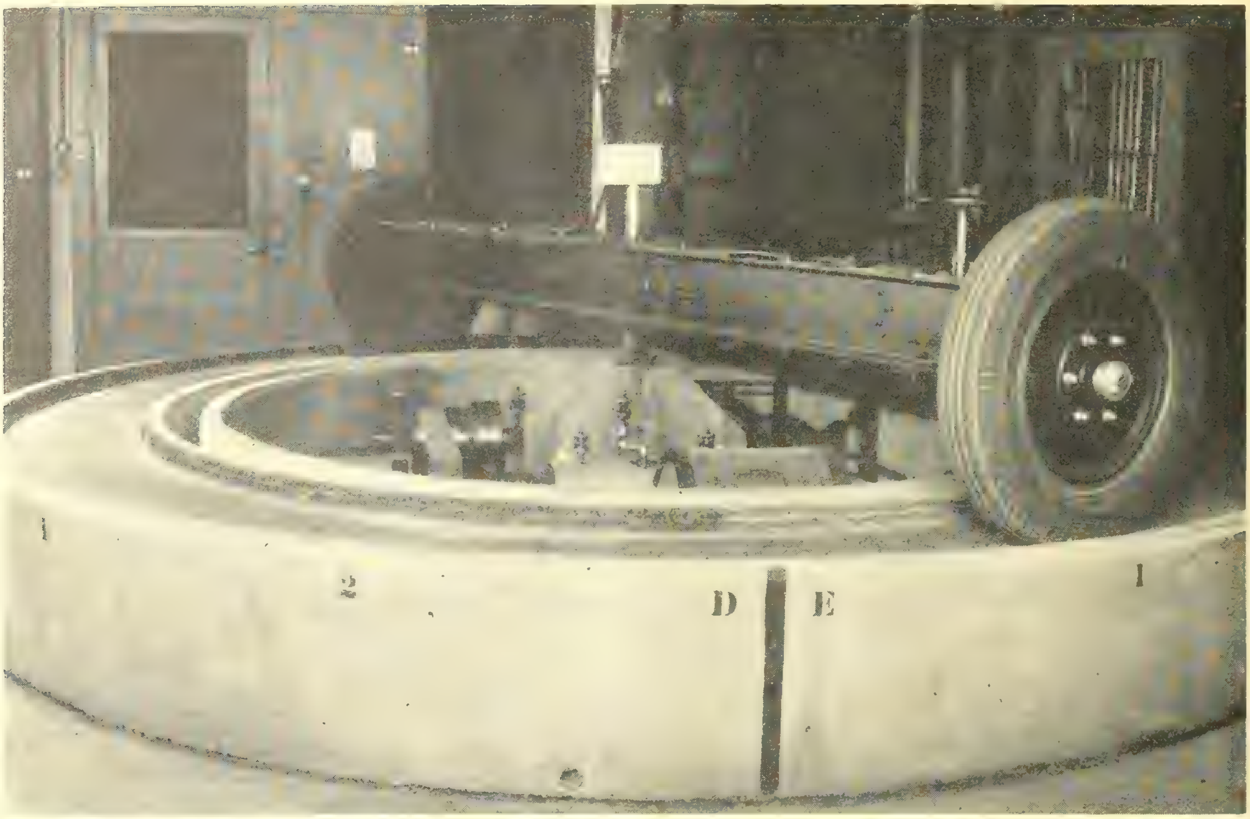


Figure 1. The Circular Test Track and Testing Apparatus. The Wheels are Resting on a Compacted Gravel Base Course.

Table 2.—*Results of tests on bituminous materials*

	Test results for materials—				
	A	B	C	D	E
Flash point, °F	300	295	310	310	490
Specific gravity, 77° F./77° F	0.952	0.972	0.976	0.985	1.006
Saybolt-Furol viscosity at 122° F., seconds	84	290	780	1,311	......
Saybolt-Furol viscosity at 140° F., seconds	......	......	335	527	......
Penetration, 100 grams, 5 seconds, 77° F	......	......	......	......	338
Float at 122° F., seconds	10	16	27	37	170
Total distillate to 437° F., percent by volume	0	0	0	0	0
Total distillate to 600° F., percent by volume	0.5	0.5	0.5	0	0
Total distillate to 680° F., percent by volume	11.0	13.0	7.0	6.0	0
Float of residue at 122° F., seconds	20	39	48	55	176
Solubility of residue in CS_2, percent	99.95	99.95	99.92	99.91	99.90
Residue of 100 penetration, percent	52	63	70	75	93

TESTS CONDUCTED TO DETERMINE THE EFFECT OF VARIATIONS IN QUANTITY AND CONSISTENCY OF THE BITUMINOUS MATERIAL

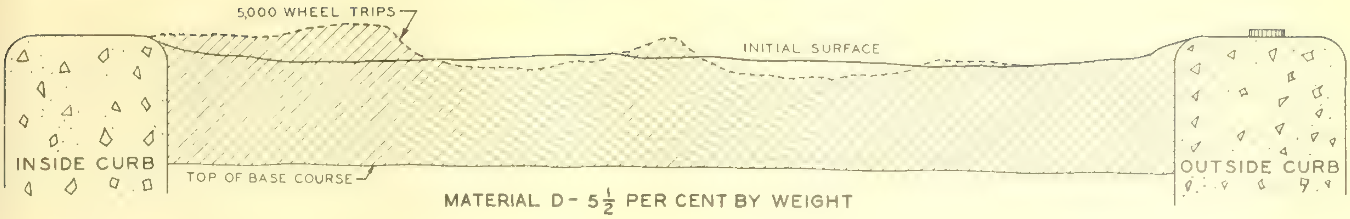
In conducting the tests on the water-free mixtures, the circular track was divided into five equal sections or one for each of the five grades of bituminous material. In each group of tests all five sections contained the same percentage of bitumen by volume. Five tracks were laid and tested, each track containing a different percentage of bitumen by volume. The percentages used, calculated on both a weight and volume basis, are given in table 3. In the following discussion all the mixtures in track 1 will be referred to as 3½-percent mixtures, those in track 2 as 4-percent mixtures, etc., and the various sections will be designed by the identification letter of the contained bitumen and the percentage of bitumen in the mixture. For instance, the section of track 1 containing material A will be referred to as section A-3½.

Table 3.—*Percentages of bituminous material used in determining the effect of quantity and consistency of the bituminous material on the performance of bituminous mixtures*

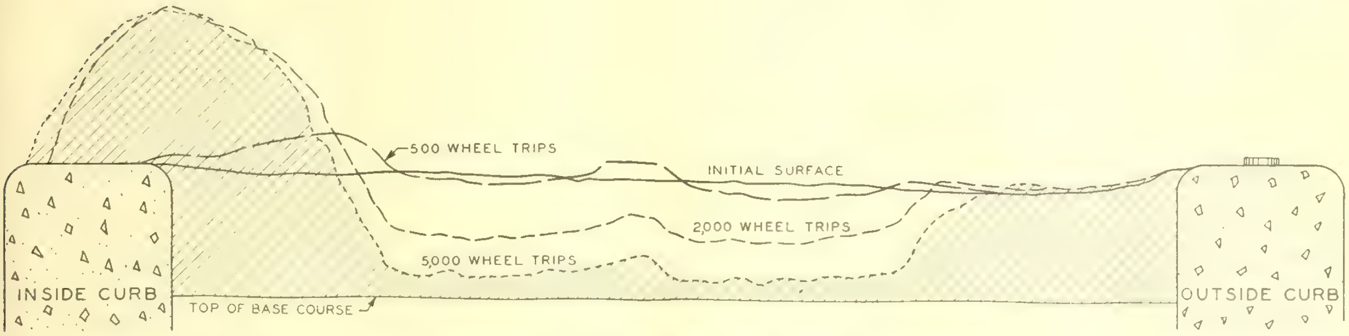
Bituminous material		Amount of bituminous material in mixtures, by weight				
Identification	Float at 122° F.	Track 1 (9.1 percent by volume)	Track 2 (10.3 percent by volume)	Track 3 (11.5 percent by volume)	Track 4 (12.7 percent by volume)	Track 5 (13.9 percent by volume)
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
A	10	3.5	4.0	4.5	5.0	5.5
B	16	3.6	4.1	4.6	5.1	5.6
C	27	3.6	4.1	4.6	5.1	5.6
D	37	3.6	4.1	4.7	5.2	5.7
E	170	3.7	4.2	4.7	5.3	5.8

About 400 pounds of each mixture was prepared, which provided enough material to lay a section 7.4 feet long and 2½ inches in compacted depth, and also provided sufficient excess material for all other tests performed on the mixture. The mixtures were prepared by hand mixing with rakes and spades in a shallow iron pan. The aggregate and bituminous material were warmed to facilitate mixing, and for material E it was necessary to heat both the stone and the bituminous material to approximately 250° F. to obtain satisfactory mixing. All mixtures except those containing material E were laid at air temperature. The E mixtures were laid at approximately 150° F., and in building each track the E mixture was laid last in order that compaction might be started while it was still at approximately that temperature.

The mixtures were placed in two layers each slightly less than 2 inches in loose thickness. The first layer was compacted by about 100 wheel trips distributed



MATERIAL D- 5½ PER CENT BY WEIGHT



MATERIAL A- 5½ PER CENT BY WEIGHT

Figure 2.—Typical Transverse Profiles from Circular Track Showing Progressive Rutting of Bituminous Mixtures Under Traffic.

over the 18 inches of track width, the compaction being held to a minimum in order to prevent the formation of a seal and resulting plane of weakness between the first and second layers. The second layer was then spread and leveled by raking and troweling, tamped with 50-pound hand tamping irons, and brushed with a hand brush to fill surface voids. Compaction was then completed by distributing the traffic of the rubber-tired wheels traveling at a speed of approximately 4½ miles per hour.

Compaction with the rubber-tired wheels was continued as long as any subsidence of the surface of any section as a whole could be produced. This required from 3,500 to 4,500 wheel trips distributed over the 18-inch track, the number of trips required to compact to "refusal" depending upon the richness of the mixtures. The lean mixtures required more traffic for compacting than did the rich ones.

Subsidence of the surface during compacting and vertical displacement during testing were measured by means of a recording profilometer, the feet of which rested on permanent brass plugs set in the curbs. Transverse profiles were taken at frequent intervals both during compacting and testing. Each section of surfacing was provided with two sets of base plugs for taking transverse profiles. Two typical series of these profiles, as traced from the original record sheets, are shown in figure 2. Figure 3 shows the profilometer with a record sheet in place.

The testing of each section for stability and resistance to wear was started as soon as compaction was completed, the beam being locked in testing position 2½ inches off center so that the wheels traveled in two concentric circular paths 5 inches apart. As ruts were formed in the less stable mixtures, ridges of displaced material were pushed up toward the two curbs. Figure 4 illustrates the appearance of some of the sections while testing was in progress.

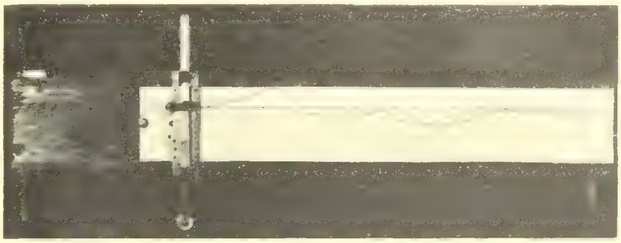
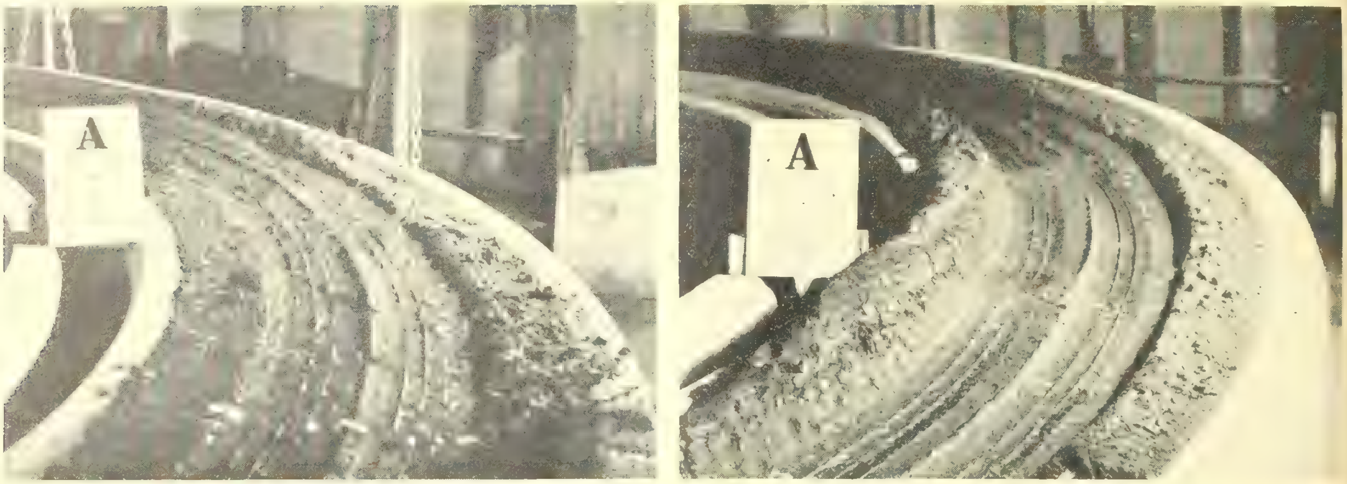


Figure 3.—The Recording Profilometer with Record Sheet in Place.

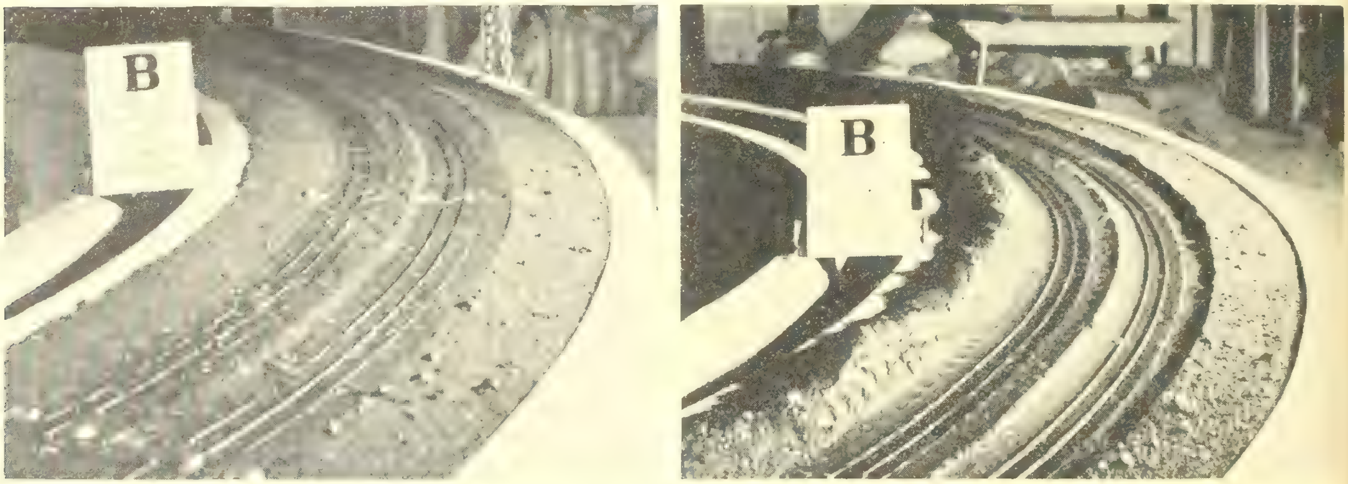
MIXTURES WITH HIGH-VISCOSITY BITUMINOUS MATERIALS HAD GREATEST STABILITIES

In figure 4 it will be noted that section A–4, although not lacking in stability, showed serious raveling, indicating insufficient bituminous material to bond the aggregate, while section A–4½ showed rutting and shoving, indicating an excess of bitumen. Section B–4 was typical of the remainder of the 4-percent mixtures, which retained smooth, even surfaces throughout the test. Section B–4½ showed considerable rutting and shoving, indicating excessive bitumen and illustrating the necessity of closely controlling the bitumen content. Comparison of C–4½ with B–4½ illustrates the effect of greater consistency of the bituminous material in reducing the tendency of the richer mixtures to shove and rut. However, in section C–5 instability was indicated by rutting, showing an excess of bitumen.

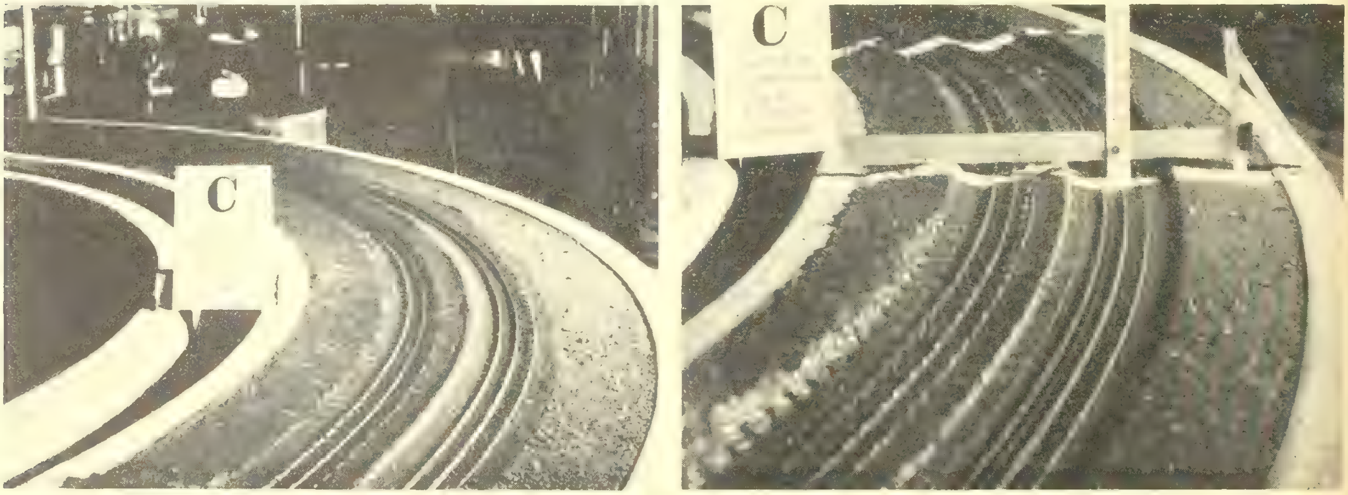
In calculating the average vertical displacement of the surface, the cross-sectional area of the ruts and the cross-sectional area of the ridges, in square inches, were measured from the profiles with a planimeter. The total of these areas divided by the width of the track (18 inches) gave the average vertical displacement. Figure 5 shows vertical displacement plotted against amount of traffic for all consistencies and proportions of bituminous materials tested. The relation of average vertical displacement to consistency and



SECTION A-4 SECTION A-$4\frac{1}{2}$



SECTION B-4 SECTION B-$4\frac{1}{2}$



SECTION C-$4\frac{1}{2}$ SECTION C-5

FIGURE 4.—APPEARANCE OF SOME OF THE BITUMINOUS MIXTURES DURING TESTING.

amount of bitumen is shown in figure 6, which was developed by taking vertical displacement at 5,000 trips from figure 5 and plotting it against percentage of bitumen in the mixture. Brass plugs were set in the surfaces and observed for forward movement of the surfacing material. Measurements showed that shoving was, in general, proportional to vertical displacement. Vertical and longitudinal displacements and numerical ratings of the test mixtures on the basis of both are given in table 4.

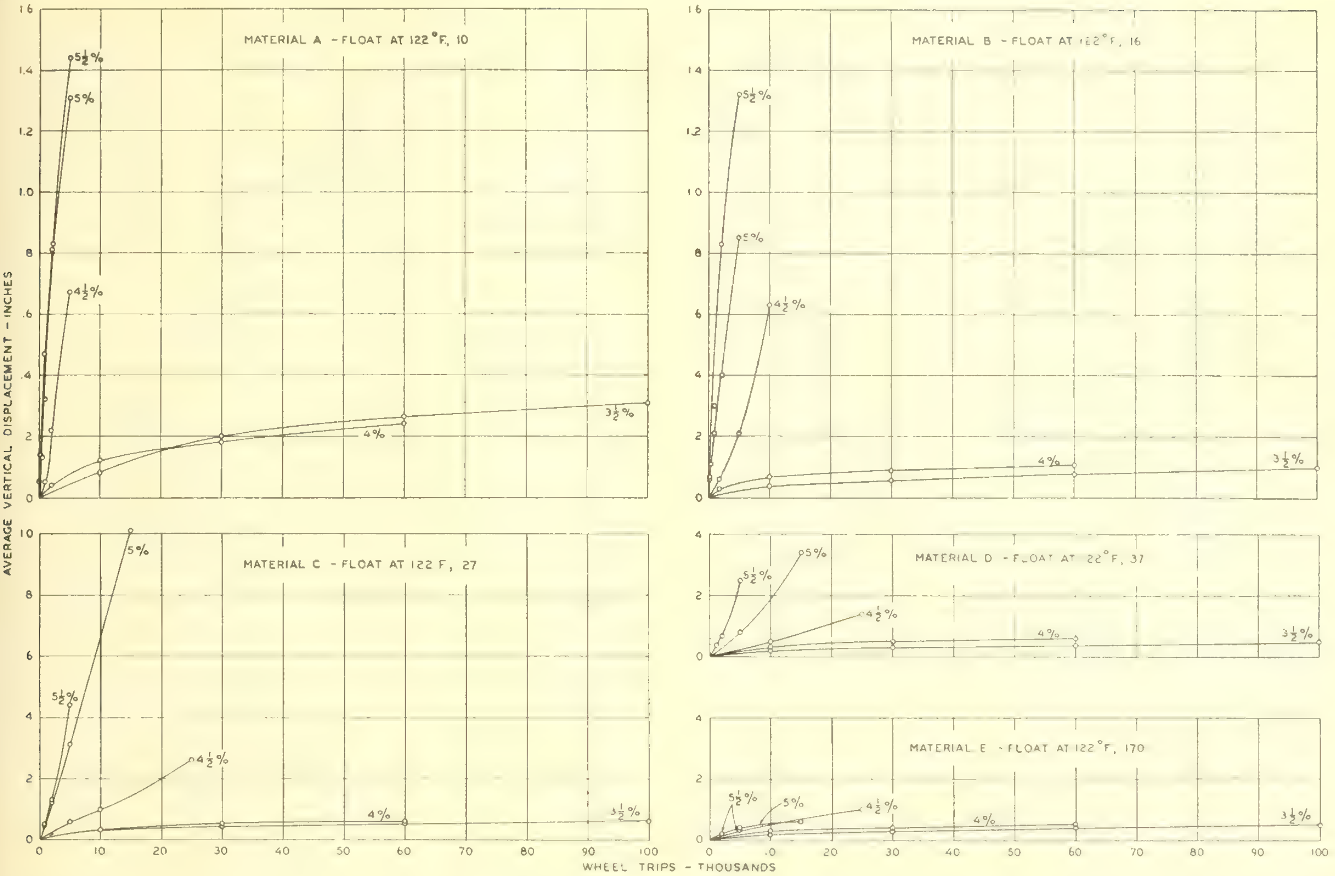


FIGURE 5.—RELATION OF VERTICAL DISPLACEMENT TO NUMBER OF WHEEL TRIPS FOR VARIOUS KINDS AND PERCENTAGES OF BITUMEN. APPROXIMATE PERCENTAGES OF BITUMEN BY WEIGHT OF MIXTURES ARE SHOWN ON INDIVIDUAL CURVES.

TABLE 4.—*Stability and rating of mixtures as measured by vertical displacement and by longitudinal displacement*

Mixture identification	Rutting caused by first 5,000 wheel trips		Shoving caused by 2,000 wheel trips	
	Vertical displacement	Rating	Horizontal displacement	Rating
	Inches		*Inches*	
E-3½	0.01	1	0	1
E-4	.01	1	0	1
D-3½	.01	1	0	1
D-4	.01	1	0	1
D-4½	.01	1	.01	2
C-3½	.02	2	0	1
C-4	.02	2	0	1
B-3½ [1]	.02	2	0	1
E-4½	.03	3	0	1
E-5	.03	3	0	1
E-5½	.03	3	0	1
A-3½ [1]	.04	4	0	1
C-4½	.05	5	.14	4
B-4	.06	6	0	1
D-5	.08	7	.04	3
A-4 [1]	.08	7	.01	2
B-4½	.23	8	.56	6
D-5½	.24	9	1.20	7
C-5	.31	10	.25	5
C-5½	.44	11	2.16	10
A-4½	.67	12	1.36	8
B-5	.85	13	1.68	9
A-5	1.31	14	3.24	11
B-5½	1.32	14	8.00	12
A-5½	1.44	15	11.00	13

[1] Failed by surface raveling.

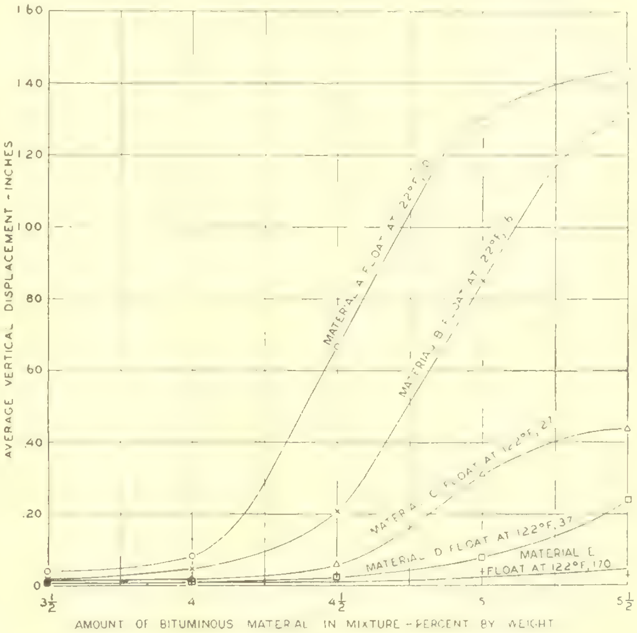


FIGURE 6.—RELATION OF CONSISTENCY AND PERCENTAGE OF BITUMEN TO VERTICAL DISPLACEMENT AFTER THE FIRST 5,000 WHEEL TRIPS.

The amounts of vertical and longitudinal displacement of the surface, given in table 4 and shown graphically in figures 5 and 6, give an excellent indication of the relative stability or resistance to plastic flow of the mixtures under moving wheel loads. The untreated sand-clay-gravel base [1] and all of the sections of oil-processed surface containing up to 4 percent of bituminous material showed a high degree of resistance to

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[1] No measurements of displacement are given on the untreated base, since no measurable shoving or rutting occurred.

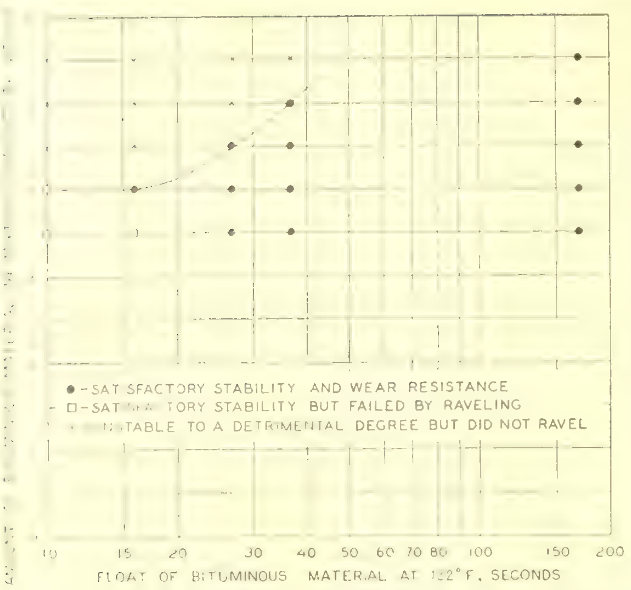

Figure 7.—Relations Between Consistency and Quantity of Bitumen in the 25 Test Mixtures and Their Condition After 5,000 Wheel Trips.

vertical and longitudinal displacement, as did a limited number of the richer mixtures in which the heavier grades of bituminous material were used.

EXCESS OF BITUMEN MOST DETRIMENTAL IN MIXTURES CONTAINING LOW-VISCOSITY BITUMINOUS MATERIALS

Purely from a consideration of resistance to internal movement or flow, the data indicate that the effect of adding liquid bituminous material to the aggregate is to reduce its stability. While this reduction in stability is not particularly detrimental until the bitumen content of the mixture reaches a certain critical percentage, the reduction takes place very rapidly after the critical percentage has been exceeded. It is apparent that this critical percentage was not reached for the semisolid material E. The data also indicate that a large loss of stability is caused by a relatively small excess of the light material A, while the more viscous materials permit the use of proportionately higher percentages of bitumen before the critical point is reached.

Figure 7 shows relations between the variables in the 25 mixtures tested. The abscissae are consistencies of the bituminous materials plotted on a logarithmic scale and the ordinates are percentages of bituminous material in the mixtures. The curve connecting the points representing the richest stable mixtures for the respective grades of bituminous material is the approximate upper oiling limit for the materials and conditions of these tests.

The mixtures whose behavior and appearance under the concentrated traffic test showed satisfactory stability were found to have had average vertical displacements of 0.1 inch or less after 5,000 wheel trips. The minimum average vertical displacement for any section was 0.01 inch and the maximum for the 16 sections having satisfactory stability was 0.08 inch. These are the first 16 sections listed in table 4. The remaining nine mixtures showed much greater vertical displacements accompanied by indications of distress such as corrugations and cracks in the surfaces. For these nine sections the average vertical displacement ranged from 0.23 inch to 1.44 inches.

In considering the loss of stability of the aggregate caused by the addition of liquid bituminous material, it is important not to lose sight of the very definite reasons for adding these materials to aggregates in low-cost road construction. The bitumen is added primarily to bond the surface aggregate together into a more or less tough, flexible skin, thus preventing the loss of surfacing material by dusting and raveling and preventing the entrance of surface water into the road structure.

In this connection, it was observed that the untreated gravel base, as well as three of the mixtures containing low percentages of bitumen and having high stability, showed serious loss of material by raveling. The mixtures failing in this way were mixtures A–3½, A–4, and B–3½.

Results obtained for the five mixtures containing material B clearly illustrate the effect of variations in quantity of bitumen on the serviceability of the treated surface. Mixture B–3½, as noted, failed by raveling resulting from insufficient bitumen; mixture B–4 was satisfactory; and mixtures B–4½, B–5, and B–5½ showed progressive degrees of rutting, indicating lack of stability caused by overoiling.

The consistency of the bitumen was found to be of more importance than quantity in affecting both the stability and sealing characteristics of the mixtures. Use of the low-viscosity material, A, resulted in no satisfactory mixtures, these mixtures failing either from raveling caused by leanness or by rutting caused by overoiling. Use of the next heavier grade, B, resulted in one satisfactory mixture with 4 percent of bitumen; use of the next grade, C, produced three satisfactory mixtures, namely, those containing 3½, 4, and 4½ percent of bitumen; and material D was satisfactory in four percentages, from 3½ to 5, inclusive, and showed low stability only in mixture D–5½.

It is evident from the test data that the use of a low-viscosity material requires the imposition of extremely close limits on the permissible bitumen content of the mixture, while the use of more viscous materials allows a much wider variation in bitumen content without sacrificing either stability or wear resistance.

DENSITY OF MIXTURES AFFECTED BY METHOD OF COMPACTION AND AMOUNT AND CONSISTENCY OF BITUMEN

Determinations of density and percentage of voids were made on all of the mixtures tested. These determinations were made on specimens taken from the track surface after compaction under distributed traffic and also on specimens taken from ruts after the completion of the concentrated traffic tests. In addition, specimens of each mixture were compacted in the Bureau's molding machine [2] by rolling 1 minute with a load of 200 pounds per linear inch of roller width and 4 additional minutes with a load of approximately 400 pounds per inch of roller width. Densities and percentages of voids were determined on these specimens, as well as on specimens compacted in a 6-inch cylindrical mold by 100 blows of a 3-pound mallet.[3] Table 5 gives the results of the density tests on the mixtures as compacted by the various methods.

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[2] See A Machine for Molding Laboratory Specimens of Bituminous Paving Mixtures, by J. T. Pauls, Public Roads, vol. 10, no. 2, April 1929.

[3] Method described in The Road-Mix Manual, no. 1, issued by the Asphalt Institute.

TABLE 5.—*Densities of bituminous mixtures compacted by various methods*

Track no.	Mixture identification	Bitumen in mixture		Percentage of voids in compacted mixture							
				Compacted in 6-inch cylindrical mold with 3-pound mallet		Compacted in roller molding machine		Circular track			
								After compacting with distributed traffic		After testing with concentrated traffic	
		By weight	By volume	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids	Mixture voids	Aggregate voids
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	A-3½	3.5	9.1	15.1	22.8	15.2	22.9	13.7	21.6	8.6	16.9
	B-3½	3.6	9.1	19.5	26.8	14.8	22.6	13.2	21.1	10.8	18.9
	C-3½	3.6	9.1	20.8	28.0	14.4	22.2	13.8	21.6	13.0	20.9
	D-3½	3.6	9.1	23.5	30.4	15.1	22.8	14.6	22.4	13.6	21.5
	E-3½ [1]	3.7	9.1	24.2	31.1	15.0	22.7	17.4	24.9	16.2	23.8
	Average				27.8		22.6		22.3		20.4
2	A-4	4.0	10.3	15.4	24.1	12.7	21.7	9.8	19.2	6.1	15.8
	B-4	4.1	10.3	18.7	27.1	12.1	21.2	10.2	19.5	6.5	16.1
	C-4	4.1	10.3	19.1	27.3	13.4	22.3	10.5	19.7	9.3	18.7
	D 4	4.1	10.3	20.7	28.9	13.4	22.3	10.3	19.6	9.8	19.2
	E-4 [1]	4.2	10.3	21.1	29.1	13.4	22.3	16.3	25.1	15.0	23.8
	Average				27.3		22.0		20.6		18.7
3	A-4½	4.5	11.5	13.7	23.7	8.2	18.8	5.2	16.1	2.3	13.5
	B-4½	4.6	11.5	15.9	25.6	9.8	20.2	7.0	17.7	3.4	14.5
	C-4½	4.6	11.5	18.3	27.8	10.7	21.0	8.6	19.1	2.9	14.1
	D-4½	4.7	11.5	19.9	29.2	11.4	21.6	11.3	21.5	4.6	15.6
	E 4½ [1]	4.7	11.5	23.2	32.0	10.6	20.9	14.7	24.5	10.3	20.6
	Average				27.7		20.5		19.8		15.7
4	A 5	5.0	12.7	10.2	21.5	5.5	17.3	1.3	13.9	1.2	13.7
	B-5	5.1	12.7	14.3	25.2	5.3	17.3	1.9	14.4	1.6	14.1
	C-5	5.1	12.7	17.0	27.5	7.5	19.2	5.1	17.2	3.0	15.3
	D 5	5.2	12.7	19.8	30.1	9.0	20.6	7.7	19.5	3.2	15.3
	E-5 [1]	5.3	12.7	20.7	30.8	9.4	21.0	13.0	24.1	11.0	22.3
	Average				27.0		19.1		17.8		16.1
5	A-5½	5.5	13.9	10.4	22.9	7.5	20.4	5.1	18.3	2.3	15.9
	B 5½	5.6	13.9	13.5	25.5	7.5	20.4	6.6	19.6	3.4	16.8
	C-5½	5.6	13.9	16.9	28.5	7.3	20.2	6.9	19.8	2.4	16.0
	D-5½	5.7	13.9	18.9	30.2	8.5	21.2	8.0	20.8	4.7	17.9
	E 5½ [1]	5.8	13.9	22.0	32.8	13.1	25.2	10.6	23.0	9.0	21.6
	Average				28.0		21.5		20.3		17.6
	Average of all mixtures				27.6		21.1		20.2		[2] 17.7

[1] All mixtures containing material E were compacted at approximately 150° F. All others were compacted at laboratory temperature.

[2] The voids content of the untreated dry aggregate compacted in a 4-inch cylindrical mold by vibrating 5 minutes with an electric hammer was 17.5 percent.

The data in table 5 are based on the following relations between mixture voids, aggregate voids, and aggregate and bitumen volumes. For the sake of brevity the following notations are used.

S=the total volume of a specimen of the compacted mixture.

A=the partial volume of the specimen occupied by the aggregate.

B=the partial volume of the specimen occupied by bitumen.

V=the volume of the voids or the partial volume of the specimen occupied by air.

$a=\frac{A}{S}\times 100$=the percentage of aggregate in the compacted specimen, by volume.

$b=\frac{B}{S}\times 100$=the percentage of bitumen in the compacted specimen, by volume.

$v_m=\frac{V}{S}\times 100$=the percentage of air in the compacted specimen, by volume.

v_a=the percentage of aggregate voids, by volume, in the compacted specimen—space occupied by air and bituminous material.

Then $A+B+V=S$

$$\text{and } \frac{A}{S}\times 100+\frac{B}{S}\times 100+\frac{V}{S}\times 100=\frac{S}{S}\times 100 \qquad (1)$$

$$\text{or } a+b+v_m=100 \qquad (2)$$

$$\text{also, } b+v_m=v_a \qquad (3)$$

In table 5 the percentage of bitumen by volume is expressed, not as a percentage of the volume of the compacted specimen, but as a percentage of the solid volume (aggregate plus bitumen), or $\frac{B}{A+B}\times 100$. This was done in order to show that the relation of the volume of bitumen to total solid volume was the same for all five sections in any individual track. This percentage, which is designated b', may be converted to an expression of the percentage of bitumen by volume of a particular specimen by multiplying it by the ratio of solid volume to total volume, $\frac{(100-v_m)}{100}$, in the specimen under consideration. Then equation (2) becomes

$$a+\frac{b'\ (100-v_m)}{100}+v_m=100 \qquad (4)$$

and equation (3) becomes

$$\frac{b'\ (100-v_m)}{100}+v_m=v_a \qquad (5)$$

As an example of the application of equation (5), the percentage of voids, v_m, for mixture A–3½, table 5, compacted in the 6-inch mold was 15.1 percent.

The percentage of bitumen by volume of solids was 9.1. Then from equation (5)

$$\frac{9.1\,(100-15.1)}{100}+15.1=r_a=22.8$$

as given in the table.

In table 5 the aggregate voids remaining after each method of compaction and after concentrated traffic are averaged for each bitumen content and grand averages are shown in each group for all five bitumen contents. Comparison of these average void contents indicates that of the three methods of compaction used, the cylinder method using a 3-pound mallet was least effective, rolling with distributed traffic was most effective, while the molding machine gave densities that were intermediate between those produced by the other two methods. The application of concentrated traffic on the track sections previously compacted under distributed traffic produced an appreciable amount of additional compaction in all of the sections, as indicated by their reduced void contents, and resulted in lower average void contents than were produced by any of the three methods of compaction used in these tests. The average void contents of the sections after testing under concentrated traffic were from 1.7 to 4.1 percent less than those of the same sections after compaction under distributed traffic; they were from 2.2 to 4.8 percent less than the average void contents of the specimens compacted in the roller molding machine; and they were from 7.4 to 12 percent less than the average void contents of the mallet-compacted specimens.

RELATIONSHIP FOUND TO EXIST BETWEEN STABILITY OF BITUMINOUS MORTAR AND STABILITY OF ENTIRE MIXTURE

Vibratory compaction tests on the dry aggregate gave a percentage of aggregate voids of 17.5, or 0.2 percent less than the average of the computed aggregate voids in all of the track sections after the concentrated traffic test. The least dense sample from the track after the concentrated traffic test, exclusive of mixtures containing the semisolid asphalt E, contained 21.5 percent aggregate voids and the most dense had 13.5 percent. It should be noted, therefore, that while the void content of the vibrated dry aggregate checked the average aggregate void content of the track specimens and was lower than that found by any other of the pre-compaction methods tried, it did not give the maximum obtainable compaction as evidenced by the lower aggregate void contents found in 14 of the track sections after the concentrated traffic test. Since the method used to obtain compaction by vibration is susceptible to considerable improvement, it is possible that the dry aggregate might be compacted to void contents comparable to those found in these 14 denser mixtures by an improved method.

Table 5 also shows that the concentrated traffic test, as well as all of the methods of compaction used, generally produced a considerably denser arrangement of the aggregate particles in the light oil mixtures than in those containing the more viscous materials. In the track sections after testing with concentrated traffic, as a typical example, the average computed aggregate voids ranged from 15.2 percent for the A mixtures to 22.4 percent for the E mixtures, or a variation of 7.2 percent resulting from differences in consistency of the bitumens.

The quantity of bitumen was also a factor in causing a marked variation in the density of the aggregates. In the track sections after testing with concentrated traffic, the 3½-percent mixtures averaged 20.4 percent aggregate voids. The percentage decreased progressively for increased bitumen contents to an average of 15.7 percent of aggregate voids for the 4½-percent mixtures and then rose progressively with increased bitumen to an average of 17.6 percent of aggregate voids for the mixtures containing 5½ percent of bitumen.

Hubbard-Field stability tests were made on the fine portion or mortar from a number of the circular track mixtures and also on a number of additional mortars having intermediate and lower bitumen contents. The materials for these tests were prepared separately by weighing the necessary amounts of crushed gravel and sand passing the no. 10 sieve and the same filler material as was used in the track mixtures. These ingredients, as well as the bitumen, were proportioned to produce mortars having the same grading as the mortars contained in the track mixtures and a slightly greater range of equivalent bitumen contents. The specimens were molded in standard Hubbard-Field molds under a pressure of 3,000 pounds per square inch maintained for 1 minute. They were allowed to cure in air for 24 hours and were then tested at laboratory temperature.

The results of the Hubbard-Field stability tests are shown in figure 8. These curves, together with those shown in figure 6, indicate that very definite relations exist between the stability of the fine portion or bituminous mortar and the stability of the entire mixture. The mixtures in the track showed loss of stability with increase in bitumen content as shown in figure 6, while the mortars showed a slightly upward trend in stability up to bitumen contents of 7 to 8 percent (approximately equivalent to 3½ and 4 percent in the track mixtures) and then a very rapid loss of stability for higher bitumen contents. However, with the exception of the D–4½ and D–5 mixtures, the range of equivalent bitumen contents through the zone of rapidly falling stabilities for the mortars corresponds closely to the range of bitumen contents in the track mixtures that showed lowered stability.

RESULTS OF TESTS ON THE EFFECT OF CONSISTENCY AND AMOUNT OF BITUMINOUS MATERIAL SUMMARIZED

The tests that have been described were made on only one type and grading of aggregate, and therefore the results should not be applied indiscriminately without further research involving other aggregates, and without proper allowance for special conditions to be met. However, it is believed that the results obtained will apply in the same relative way to materials and conditions other than those of the tests. For the combinations of materials studied and the conditions of these tests the following conclusions are indicated:

1. The addition of slow-curing, liquid bituminous material to aggregate of the coarse, dense-graded type reduces its stability or resistance to lateral flow under moving loads.
2. This effect is greatest for bituminous admixtures of low viscosity and tends to become progressively less as the consistency of the bituminous admixture is increased.
3. Loss of stability, as measured by rutting of the circular track under concentrated traffic, is small up to a certain critical bitumen content and increases rapidly as the percentage of bitumen is increased above the critical point.

4. Surfacing mixtures having very low bitumen contents, although possessing relatively high stability, fail to produce well-bonded wearing surfaces, and when the consistency of the bitumen is less than about 300 Saybolt-Furol viscosity at 122° F., the surface may ravel extensively under the direct action of traffic.

5. The use of bituminous materials having a viscosity of less than approximately 300 in surfacing mixtures with the type and grading of aggregate described necessitates extremely rigid control of the bitumen content. Material B, having a viscosity of 290, produced satisfactory results in only one proportion (4 percent). Mixture B–3½ raveled, and the mixtures containing 4½ percent or more of material B rutted and shoved excessively.

6. The use of more viscous liquid bituminous materials allows greater leeway in the permissible bitumen content of the mixture. The range of bitumen contents in satisfactory mixtures was from 3½ to 5 percent for the highly viscous material D and from 3½ to 4½ percent for material C.

EFFECT OF WATER ON THE STABILITY OF BITUMINOUS MIXTURES INVESTIGATED

Following the investigation of water-free mixtures, a series of tests was conducted to study the effect of water on the stability and service behavior of similar surfacing materials.

In the first four tests in this series, the surfaces were laid on the same sand-clay-gravel base as was used in the previous studies of water-free mixtures. The bearing power and uniformity of this base was excellent as long as it remained dry or only moderately damp. However, when the base was inundated in order to introduce capillary water into the surfacing mixture, the churning action of traffic caused marked local failures in the base. These failures took the form of widely spaced corrugations and contributed so seriously to the failure of the surfacing course that it was impossible to differentiate between surface failures resulting from weakness of the surfacing mixture and those caused by base failure.

Since these studies were primarily concerned with the qualities of the bituminous wearing coarse, the sand-clay-gravel base was discarded at the end of the fourth test of the series and a crushed-limestone base substituted. In constructing the limestone base the stone was thoroughly compacted and choked with clean sand. A bonded top was then formed by raking in dry portland cement, which was wetted by introducing water from below and allowed to set without puddling. There resulted a firm, well-bonded surface having sufficient porosity to allow free passage of water to the bituminous wearing course. No further trouble was encountered from base failures even when both base and surfacing course were inundated with water. Tracks 10, 11, and 12 were laid on this base.

Seven tracks were tested in this series—tracks 6 to 12, inclusive. Figures 9 to 13 show diagrammatically the layouts, test procedures, and notations on the behavior of the test sections for tracks 6 to 10.

Although a few of the wettest surfaces rutted considerably, other more characteristic types of failure were observed on many of the wet sections. Such evidences of failure were corrugations, surface cracking, and surface peeling followed by rapid pot holing or local raveling.

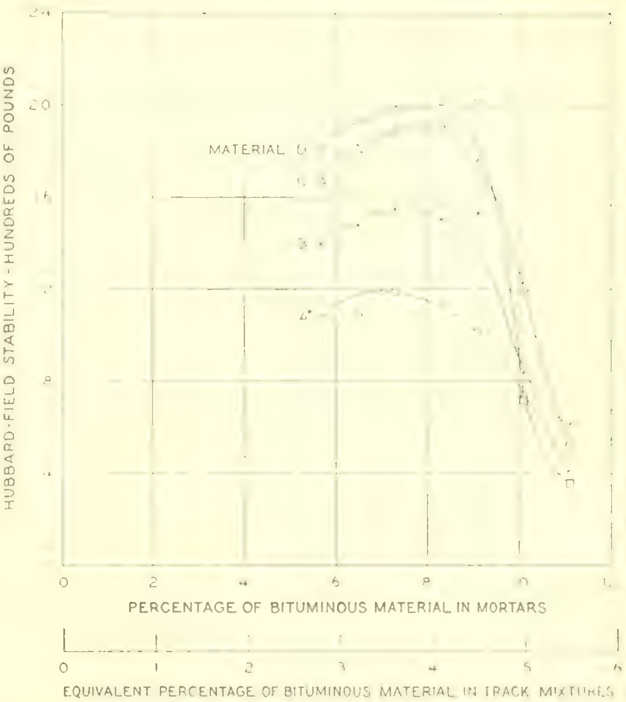
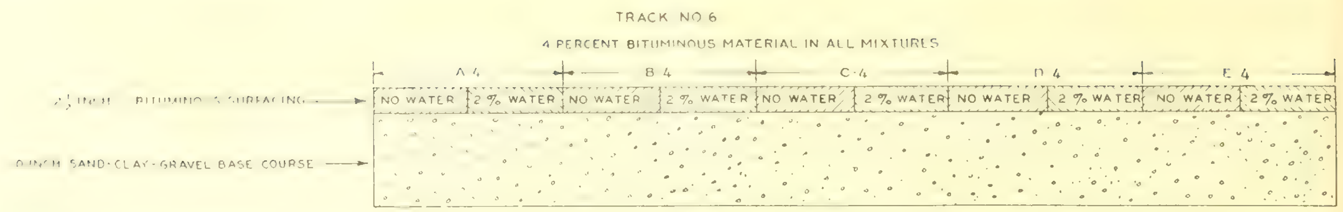


Figure 8.—Relations Between Bitumen Content and Hubbard-Field Stability of Mortars Made by Adding Bituminous Material to the Fine Portion of the Circular Track Aggregate.

As shown in figure 9, track 6 was laid in five sections, each section containing 4 percent of bitumen and each having one of the five grades of bitumen used in the previous investigation of water-free mixtures. Each section was further subdivided into two subsections, one being laid without water in the mixture and one having 2 percent of water added to the aggregate before the bitumen was applied. After compaction of the surfacing mixtures on the dry base, water was admitted to the base and the water level maintained at 9 inches below the track surface during the first 50,000 wheel trips of concentrated traffic and at 4½ inches below the surface during the last 25,000 wheel trips.

Comparison of the observed behavior of the test sections in this track clearly indicated the superiority of the mixtures containing the highly viscous to semisolid bituminous materials over the mixtures containing lighter materials in resisting the detrimental effects of water.

Although, as previously mentioned, it was difficult to distinguish between failures resulting from surface weakness and those caused by base settlement, it was observed that the sections having low viscosity bitumen in the surfacing mixtures failed earlier and to a greater extent than did those having the highly viscous to semisolid bituminous materials. Figure 9 shows the relation of time of occurrence and observed extent of failure to the amount of traffic applied. The surface on section A, where the lightest bitumen was used, raveled during and immediately following compaction and, in the early stages of the test, developed considerable corrugation. After 50,000 wheel trips of concentrated traffic, it was badly rutted in the originally dry half and somewhat less badly rutted in the half laid with 2 percent of water. Part of this rutting was undoubtedly caused by base failure, but, regardless of whether or not this was the



CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS									
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS										
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 DAYS	0	RAVELED BADLY	RAVELED SOMEWHAT	REMAINED IN GOOD CONDITION							
			4,500										
TESTING (CONCENTRATED TRAFFIC)	WATER 9 INCHES BELOW SURFACE	9 DAYS	0										
			5,000	LESS RAVELING	SLIGHT RAVELING	CRACKING							
			12,000	CORRUGATING		CORRUGATING							
			50,000	BADLY RUTTED	RUTTED	RUTTED AND CRACKED	RUTTED	SLIGHTLY RUTTED & CRACKED	SLIGHTLY RUTTED	SLIGHTLY RUTTED & CRACKED	SLIGHTLY RUTTED	SLIGHT CRACKING	
TESTING (CONCENTRATED TRAFFIC)	WATER 4½ INCHES BELOW SURFACE	6 DAYS	75,000	BASE IN ALL SECTIONS SETTLED IRREGULARLY SOON AFTER WATER LEVEL WAS RAISED THIS CAUSED GENERAL CRACKING IN ALL SECTIONS OF SURFACING BUT NO SECTION EXCEPT E SHOWED SUPERIORITY OVER THE OTHERS.									

FIGURE 9.—EFFECT OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF THE VARIOUS BITUMINOUS MATERIALS.

case, the condition of section A after the 50,000 wheel trips was clearly worse than that of any other section with the possible exception of section B in which the next heavier grade of bitumen was used.

While showing no noticeable raveling, section B developed cracks in the originally dry half and corrugations in both halves early in the test and rutted somewhat less than did section A during the 50,000 wheel trips before the water level was raised in the base.

Sections C and D, in which the two next heavier grades of bitumen were used, showed no evidence of failure until after 12,000 wheel trips of concentrated traffic had been applied, and from then until the completion of 50,000 wheel trips developed only slight cracks in the originally dry sections and a moderate amount of rutting throughout.

Section E, which contained the semisolid bituminous material, showed no evidence of failure except slight cracking in the originally dry half up to 50,000 wheel trips.

Since quantitative measurement of the rutting in track 6 was impractical because of the longitudinal irregularity of the ruts, comparison cannot be made between the performance of this track and track 2 in which the 4-percent, water-free mixtures were tested (see table 4). However, it was observed that the principal difference between these two tracks was a greater tendency on the part of track 6 to corrugate in the sections having bitumen of low viscosity, and a tendency for all sections to develop cracking. This cracking, as well as a general rutting and increased roughness, became extremely noticeable on all sections of track 6 after the water level was raised to within 4½ inches of the top of the curbs at 50,000 wheel trips. During the ensuing 25,000 wheel trips the ruts and corrugations developed rapidly in all the sections. In some places the additional displacement amounted to one-half inch or more without, however, materially changing the thickness of the surface course in the bottoms of the ruts. In other words, the additional and comparatively rapid rutting and corrugating were largely the result of base failure caused by the higher water level.

WET MIXTURES ON DRY BASES TEND TO DRY OUT AND REGAIN STABILITY

Tracks 7 and 8, data for which are shown in figures 10 and 11, were identical as to grade and quantity of bitumen and base conditions. Both contained 4 percent of material C in all sections and were laid and tested on a dry base. Both tracks were divided into five sections that varied only in the amount of water added to the aggregates before mixing with bitumen. One section in each was surfaced with a mixture prepared with air-dried aggregate containing about 0.4 percent of water but to which no water had been added. In the remaining four sections of each track, the respective mixtures were prepared from aggregates to which 2, 3, 4, and 6 percent of water had been added.

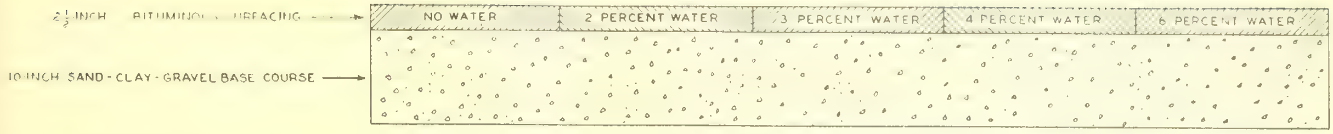
The wet sections in track 7 after compaction contained considerably less water than the amount which had been added to the aggregates. In fact, only two of them contained over 2 percent of moisture when the traffic test was started. Of these two, the section containing 2.8 percent of residual moisture developed some alligator cracks under traffic, and the section containing 5 percent of water rutted appreciably, indicating considerable loss of stability, and it also developed alligator cracks.

The section that was laid dry and the two wet sections in which the moisture content had fallen to 2 percent or less during laying and compacting showed no evidence of failure at the end of the test. The test on track 7 was concluded at 15,000 wheel trips.

Track 8 was identical with track 7 except that mixing and laying operations were speeded up somewhat to reduce the loss of water from the wet mixtures. Only 1,000 wheel trips of compacting traffic were applied so that compaction was completed and test traffic started within 4 hours after the surfacing material was laid. During both compacting and early testing the surfaces of all the sections were lightly sprinkled at intervals to retard the loss of moisture by evaporation. The actual moisture contents of the sections containing 2 percent and 3 percent of water were reasonably close to the designed contents, but the sections originally containing 4 percent and 6 percent of water actually contained only 3.4 and 4.4 percent, respectively, when testing was started. Rutting occurred only in the wettest section, as was the case in track 7. The rutting in the section originally containing 6 percent of water began as soon as concentrated traffic was started and had virtually reached its maximum at 1,000 wheel trips. After the sprinkling was discontinued (at 10,000 wheel trips of test traffic)

TRACK NO. 7

4 PERCENT OF MATERIAL C IN ALL MIXTURES



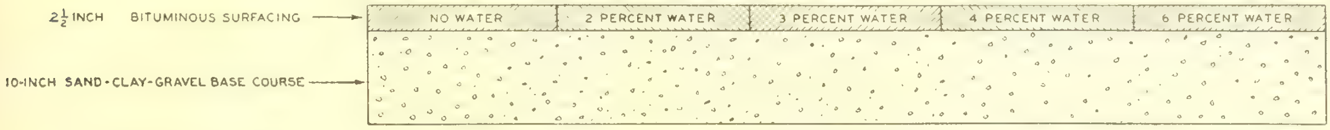
CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 DAYS	0	GOOD CONDITION WATER 0 4 PERCENT [1]	GOOD CONDITION WATER 1.3 PERCENT [1]	GOOD CONDITION WATER 2 0 PERCENT [1]	CRACKED EXTENSIVELY WATER 2.8 PERCENT [1]	CRACKED EXTENSIVELY WATER 5.0 PERCENT [1]
			3,500					
TESTING (CONCENTRATED TRAFFIC)	DRY	5 DAYS	0					
			100					RUTTING
			5,000					WATER 2.6 PERCENT
			15,000	NO EVIDENCE OF FAILURE WATER 0.4 PERCENT	NO EVIDENCE OF FAILURE WATER 1.1 PERCENT	NO EVIDENCE OF FAILURE WATER 1.6 PERCENT	EXTENSIVE CRACKS WATER 1.9 PERCENT	EXTENSIVE CRACKS NO ADDITIONAL RUTTING WATER 2.6 PERCENT

[1] WATER CONTENT DETERMINED ON LOOSE MATERIAL BEFORE APPLYING TRAFFIC

FIGURE 10.—EFFECT OF VARIOUS AMOUNTS OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF MATERIAL C.

TRACK NO. 8

4 PERCENT OF MATERIAL C IN ALL MIXTURES



CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	4 HOURS	0	LIGHT SPRINKLING STARTED				
			1,000	WATER 0.2 PERCENT [1]	WATER 2.3 PERCENT [1]	WATER 3.0 PERCENT [1]	WATER 3.4 PERCENT [1]	WATER 4.4 PERCENT [1]
TESTING (CONCENTRATED TRAFFIC)	DRY	4 HOURS	0					RUTTING STARTED IMMEDIATELY
			2,000	NO EVIDENCE OF FAILURE				WATER 2.3% VERY LITTLE RUTTING WATER 3.2% RUTTED BADLY
		3 DAYS	10,000	SPRINKLING DISCONTINUED				NO FURTHER RUTTING RUT REPAIRED
			15,000	LONGITUDINAL CRACKS				ROUGH BUT NO FURTHER RUTTING
		6 DAYS	29,000	WATER 0.3 PERCENT	WATER 1.0 PERCENT	WATER 1.6 PERCENT	WATER 1.4 PERCENT	WATER 1 9 PERCENT ROUGHER BUT NO FURTHER RUTTING
			44,000	NO FURTHER FAILURE	NO EVIDENCE OF FAILURE	SLIGHT SCALING	SLIGHT SCALING	WATER 1.3 PERCENT. SCALING, NO ADDITIONAL ROUGHNESS

[1] WATER CONTENT DETERMINED AT START OF COMPACTION PERIOD

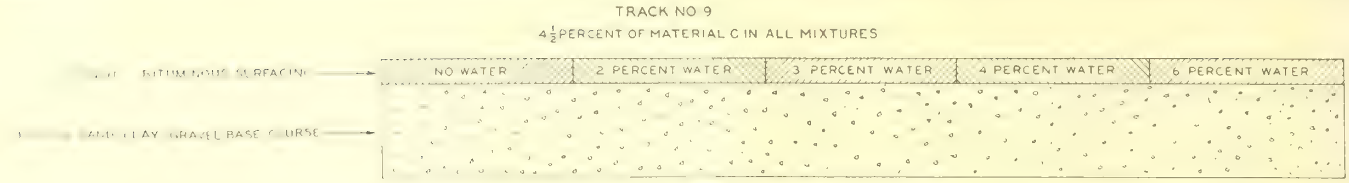
FIGURE 11.—EFFECT OF VARIOUS AMOUNTS OF WATER ON THE BEHAVIOR OF MIXTURES CONTAINING 4 PERCENT OF MATERIAL C. THE SECTIONS WERE SPRINKLED TO RETARD LOSS OF MOISTURE BY EVAPORATION.

the mixtures lost moisture so rapidly that at 29,000 wheel trips of test traffic none of them contained as much as 2 percent of water. At 44,000 wheel trips of test traffic, when the test was discontinued, the sections originally having 3, 4, and 6 percent of water showed a slight tendency to scale or peel, and the dry section had developed some longitudinal surface cracks, due probably to the light sprinkling. No indication of failure was evident in the section that originally contained 2 percent of water.

Track 9 (see fig. 12) was similar to tracks 7 and 8 except that 4½ percent of material C was used in the mixtures instead of 4 percent. Mixing and laying operations were further hastened to avoid, as much as possible, loss of moisture from the mixtures. The number of trips for compaction was reduced to 300, and compaction was finished and testing started within 2 hours after the mixtures were laid. This track was not sprinkled.

The compacted mixtures had water contents from 0.3 percent to 1 percent below the original water contents. Again, the only wet section showing reduced stability by rutting was that laid with 6 percent of water and containing 5 percent when testing with concentrated traffic was started. Rutting and corrugation developed so rapidly in this section that it had to be replaced at 1,000 wheel trips of test traffic with a more stable material in order to continue the test on the other sections. The highest moisture content in any of the other sections when testing was started was 3.1 percent. The dry section showed very slight rutting, the amount corresponding closely to that recorded for the same mixture in the tests on water-free mixtures. The failure of the wet sections containing from 1.7 percent to 3.1 percent of water to rut at all, whereas the dry section showed a normal amount of rutting, is attributed to a peculiarity of such mixtures which was observed throughout this series of test, namely, that the addition of a small amount of water (generally less than 3 percent) appeared to make the mixture harsh and hard to compact.

Low stability is a characteristic of oily, easily compacted mixtures or of mixtures that have been compacted to such an extent that virtually all their void spaces are filled with liquid. It follows, therefore, that if a small amount of water causes harshness in the mixture and thereby retards compaction, the mixtures, although having low stability when thoroughly compacted, may show a temporary stability somewhat higher than normal during the comparatively long period of traffic application necessary to bring them to their ultimate density.



CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	2 HOURS	0 300	GOOD CONDITION. WATER 0.2 PERCENT [1]	GOOD CONDITION. WATER 1.7 PERCENT [1]	GOOD CONDITION. WATER 2.3 PERCENT [1]	GOOD CONDITION. WATER 3.1 PERCENT [1]	MOVED NOTICEABLY UNDER WHEELS. WATER 5.0 PERCENT [1]
TESTING (CONCENTRATED TRAFFIC)	DRY	1½ DAYS	0					RUTTING IMMEDIATELY AND LONGITUDINAL CRACKS
			1,000					WATER 4 PERCENT. BADLY RUTTED, DISCONTINUED
			2,100	WATER 0.2 PERCENT	WATER 1.4 PERCENT	WATER 1.6 PERCENT	WATER 2.7 PERCENT	
			5,000	SOME RUTTING				
			7,800	RUTTED ¼ INCH [2]	NO RUTTING	NO RUTTING	NO RUTTING	

[1] WATER CONTENT DETERMINED ON LOOSE MATERIAL BEFORE APPLYING TRAFFIC.

[2] MAXIMUM DEPTH OF RUT AT ANY POINT.

Figure 12.—Effect of Various Amounts of Water on the Behavior of Mixtures Containing 4½ Percent of Material C

MIXTURES WITH HIGH BITUMEN CONTENTS ABSORBED LEAST WATER FROM BASE COURSE

Track 10 (see fig. 13) consisted of five sections, all containing material C but in amounts varying by increments of one-half percent from 3½ to 5½ percent of bitumen. The mixtures were laid without the addition of water and the base was kept dry during compaction of the surfacing mixtures. After the sections were compacted by 3,000 wheel trips, 4,000 additional wheel trips of distributed traffic were applied with the base flooded to within one-fourth inch of the bottom of the bituminous mat.

None of the sections showed any indication of failure except that the sections containing 5 and 5½ percent of bitumen showed a normal low stability resulting from their high bitumen contents. The water was then raised to within 1½ inches of the top of the bituminous mat and 1,700 additional wheel trips were applied, making a total of 5,700 wheel trips of distributed traffic. The mixtures were then tested for water content. The results of these tests are shown in figure 13 opposite the first entry of 5,700 wheel trips.

At that time the sections containing 3½, 4, and 4½ percent of bitumen were still in good condition, but the section containing 5 percent was badly cracked and the section containing 5½ percent was rubbery and unstable. The water level was again raised, this time to within one-fourth inch of the top of the bituminous mat, and maintained there without additional traffic for 18 hours or three-fourths of a day. The sections were again tested for water content and the results are shown in figure 13 opposite the second entry of 5,700 wheel trips. All of these tests of water content were made only on the top inch of the mixtures.

The first test of water content indicated that capillarity and the action of traffic had caused some water to rise above the free water level into the top half of the bituminous mixtures. As shown in figure 13, the amounts ranged from 0.5 percent for the mixture containing 3½ percent of bitumen to 2.1 percent for the mixture with 4½ percent of bitumen, and then downward to 0.7 percent for the mixture with 5½ percent of bitumen.

During the 18 hours when the water level was within one-fourth inch of the top of the bituminous mat and no traffic was being applied, upward percolation caused the water content in the top inch of the mixtures having 3½ and 4 percent of bitumen to increase to 2 percen and 1.5 percent, respectively. No increase in wate content occurred in the top inch of the other thre sections having 4½, 5, and 5½ percent of bitumen. O the contrary there was a very slight decrease, whic probably was the result of the inability of the water t percolate upward through these richer and, by then well-compacted mixtures fast enough to offset th losses by surface evaporation.

The water level was next lowered to 1½ inches belo the top of the mat and maintained at this level durin the application of 3,300 additional wheel trips o distributed traffic. This brought the total of a distributed test traffic on this track up to 9,000 whee trips. At 9,000 wheel trips the water content wa determined both at the top and bottom of each section The results are shown in figure 13.

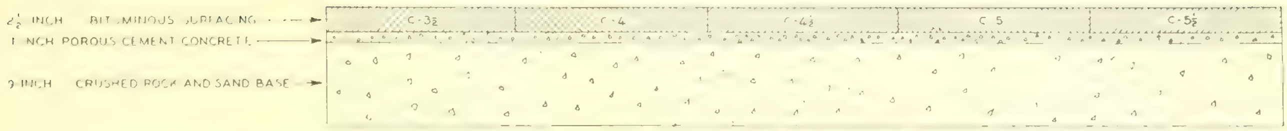
In the top inch, the mixtures having 3½ and 4 percen of bitumen showed additional gains in water conten of 0.6 and 0.4 percent, respectively. The mixtur with 4½ percent of bitumen showed no change in wate content and those with 5 and 5½ percent of bitume showed additional losses of 0.1 and 0.3 percent, respectively. The bottom inch of each section containe a considerably higher percentage of water than did th top inch. In both the top and bottom inch, comparin the various sections, the water content decrease progressively with higher bitumen contents. At thi time the sections containing 3½, 4, and 4½ percent o bitumen were in good condition and those containin 5 and 5½ percent of bitumen both showed alligato cracking and were wavy and highly plastic.

In the final phase of the test, the water level wa lowered to the bottom of the bituminous mat an concentrated traffic was applied. The mixtures havin 5 and 5½ percent of bitumen failed immediately unde this type of traffic and after 500 wheel trips wer replaced with other material to allow completion of th test on the remaining sections.

It is of interest in connection with the failure of thes two sections that when they began to rut, the surfac cracks opened up and after about 200 wheel trips considerable quantity of mud was ejected throug them. This mud, although appearing from its colo and texture to contain no bitumen, proved upo analysis to contain 8.9 percent of bitumen on the basi of its water-free weight. Its water content was 2 percent. The bitumen in this ejected material ha

TRACK NO 10

MATERIAL C IN ALL SECTIONS. NO WATER ADDED TO MIXTURES


2½ INCH BITUMINOUS SURFACING
1 INCH POROUS CEMENT CONCRETE
9 INCH CRUSHED ROCK AND SAND BASE
C-3½
C-4
C-4½
C-5
C-5½

CONDITIONS OF THE TEST				BEHAVIOR OF TEST SECTIONS				
OPERATION	BASE CONDITION	TIME	NUMBER OF WHEEL TRIPS					
COMPACTING (DISTRIBUTED TRAFFIC)	DRY	2½ DAYS	0					
			3,000					
TESTING (DISTRIBUTED TRAFFIC)	WET. WATER ½ INCH BELOW BITUMINOUS COURSE	3 DAYS	0				GOOD CONDITION	GOOD CONDITION
			4,000	GOOD CONDITION	GOOD CONDITION	GOOD CONDITION	MOVED SLIGHTLY UNDER WHEELS	MOVED CONSIDERABLY UNDER WHEELS
	WET. WATER 1½ INCH BELOW TOP OF BITUMINOUS COURSE	3 DAYS	5,700 1/	WATER, TOP, 0.5 PERCENT	WATER, TOP, 0.6 PERCENT	WATER, TOP, 2.1 PERCENT	CRACKED EXTENSIVELY WATER, TOP, 1 [illegible] PERCENT	RUBBERY, UNSTABLE WATER, TOP, 0.7 PERCENT
			5,700 1/	WATER, TOP, 2.0 PERCENT	WATER, TOP, [illegible] 5 PERCENT	WATER, TOP, 1.8 PERCENT	WATER, TOP, 0.9 PERCENT	WATER, TOP, 0.6 PERCENT
			9,000	PEELING AND PITTING WATER, TOP, 2.6 PERCENT BOTTOM, 5.3 PERCENT	PEELING AND PITTING WATER, TOP, 1.9 PERCENT BOTTOM, 3.9 PERCENT	SLIGHT PEELING & PITTING WATER, TOP, [illegible] 8 PERCENT BOTTOM, 3.0 PERCENT	CRACKED EXTENSIVELY WAVY, UNSTABLE WATER, TOP, 0.8 PERCENT BOTTOM, 2.4 PERCENT	CRACKED EXTENSIVELY WAVY, UNSTABLE WATER, TOP, [illegible] PERCENT BOTTOM, 2 [illegible] PERCENT
TESTING (CONCENTRATED TRAFFIC)	WET. WATER IN CONTACT WITH BOTTOM OF BITUMINOUS COURSE	5 DAYS	0				RUTTED IMMEDIATELY	
			200				MUD EJECTED THROUGH CRACKS 2/	MUD EJECTED THROUGH CRACKS AND AT CURB 2/
			500	CRACKS BEGINNING TO DEVELOP			DISCONTINUED	DISCONTINUED
			1,500		CRACKED EXTENSIVELY	CRACKED EXTENSIVELY		
			3,700	CRACKED EXTENSIVELY	MUD EJECTED 2/			
			6,800	MUD EJECTED 2/				
			8,000			MUD EJECTED 2/		
			8,000	TEST STOPPED. SECTIONS BADLY POT-HOLED AND RAVELED				

1/ AT 5,700 TRIPS WATER CONTENT TESTED AND WATER LEVEL RAISED TO ½ INCH OF TOP OF BITUMINOUS COURSE AND ALLOWED TO STAND 18 HOURS WATER CONTENT AGAIN TESTED AND SHOWED THE CHANGES INDICATED WATER LEVEL THEN RETURNED TO ½ INCHES BELOW TOP OF BITUMINOUS COURSE

2/ THIS MUD CONTAINED 25 PERCENT WATER AND OF THE WATER-FREE MATERIAL 8.9 PERCENT WAS BITUMINOUS MATERIAL

FIGURE 13.—EFFECT OF WATER AND BITUMEN CONTENT ON THE BEHAVIOR OF MIXTURES CONTAINING VARIOUS PERCENTAGES OF MATERIAL C.

apparently been completely emulsified by the action of traffic on the water-soaked surfacing mixture.

Figure 14, which shows the section containing 5 percent of material C after 500 wheel trips of concentrated traffic, illustrates the condition of this section and the section containing 5½ percent of material C when they were discarded.

The sections with 3½, 4, and 4½ percent of bitumen developed surface cracks at 500 wheel trips and some mud was ejected through the cracks in all three sections before the conclusion of the test. The section having 4½ percent of bitumen was the last of the five to eject the mud and oil emulsion and was apparently least affected by the action of moisture. The test was concluded at 8,000 wheel trips.

The water conditions for track 10 were purposely made extremely severe in order to accelerate the test and to show, as clearly as possible, the comparative differences in behavior of the sections. The tests indicated that the susceptibility of these mixtures to damage from excessive moisture increased as their bitumen contents were increased above 4½ percent. This is evidenced both by the shorter time required to produce failure of the rich sections compared with the lean ones, and by the greater extent of the failure in the rich sections for a given amount of traffic.

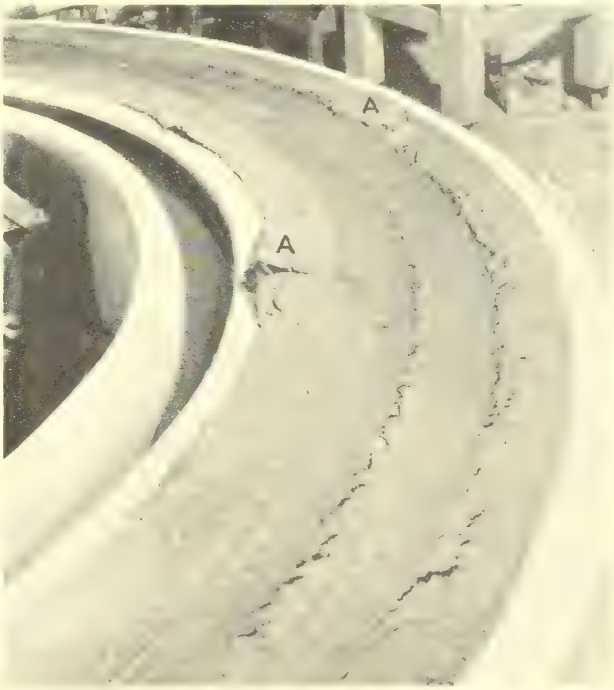


FIGURE 14.—SECTION OF TRACK NO. 10 CONTAINING 5 PERCENT OF MATERIAL C, AFTER 9,000 WHEEL TRIPS OF DISTRIBUTED TRAFFIC AND 500 WHEEL TRIPS OF CONCENTRATED TRAFFIC. MUD WAS EJECTED FROM THE SPOTS MARKED "A".

ADDING WATER TO AGGREGATE FOUND LESS DETRIMENTAL THAN ADDING WATER TO OILED MIXTURE

Comparison of the results of the tests on track 10 with those on tracks 7, 8, and 9, in which water was contained in the mixtures but not in the base, indicates that water in the base structure is a more serious cause of failure than moisture in the surfacing mixtures when the base is dry. This is due to the fact that a wet base tends to maintain the surfacing mixture in a wet, unstable, and generally weakened condition for as long a time as drainage conditions remain unsatisfactory; whereas, if the base is well drained and dry, a wet mixture placed on top of it will, under favorable weather conditions, dry out and become stable in a comparatively short time. It should be noted, however, that in several instances test mixtures which contained more than 2½ to 3 percent of moisture when the test traffic was started, even when the base course was dry, developed alligator cracks which failed to heal after the mixtures had partially dried. It was observed that cracks, once formed, persisted until the surface was broken up and remixed.

Tracks 11 and 12 were designed to show the effect of (*a*) water contained in the aggregate at the time of applying the bitumen, and (*b*) water incorporated in the mixture after oiling but before compacting. Each of these two tracks was divided into six sections, three of which were surfaced with mixtures containing 4½ percent of material B and the other three with mixtures containing 4½ percent of material D. In track 11 water was added to the aggregate 24 hours before applying the bitumen, and in track 12 water was added and mixed into the oiled aggregate 24 hours before the track was laid and compacted. In both tracks the percentages of water used were, on the basis of the weight of the dry aggregate, 2, 4, and 6 percent for the B and also for the D bituminous mixtures.

These two tracks were each given only 300 wheel trips of distributed traffic for compaction, due to the extremely low stability of the mixtures with material B containing 6 percent of water. Further compaction of these mixtures would have resulted in pushing a large part of the material out of the track and over the curb. Two of the mixtures containing material B, that having 6 percent of water added to the aggregate (track 11) and that having 6 percent of water added to the mixture (track 12), failed completely within the first 600 wheel trips of concentrated traffic and had to be replaced with more stable material before the tests could be continued on the other sections. All but two of the sections showed average vertical displacements in excess of 0.1 inch at 5,000 wheel trips, which would cause them to be classified as unsatisfactory according to the procedure followed in the classification of the water-free mixtures previously discussed in this report. The two exceptions were the mixtures with material D containing 2 and 4 percent water added to the aggregates.

The average vertical displacements at 5,000 wheel trips for the mixtures in tracks 11 and 12 are given in table 6. Comparison of these data with the data given in table 4 for the water-free mixtures clearly shows the effect of water in lowering the stability of these bituminous mixtures.

TABLE 6.—*Average vertical displacement of bituminous mixtures after 5,000 wheel trips*

[Tracks 11 and 12; 4½ percent of bitumen in all sections]

Track no.	Material	Water		Average vertical displacement at 5,000 wheels trips
		Percent	Added to—	
				Inches
11	B	2	Aggregate	0.29
11	B	4	do	.29
11	B	6	do	(1)
12	B	2	Oiled mixture	.32
12	B	4	do	[2] 1.92
12	B	6	do	(1)
11	D	2	Aggregate	.10
11	D	4	do	.10
11	D	6	do	[2] 1.02
12	D	2	Oiled mixture	.17
12	D	4	do	.50
12	D	6	do	.58

[1] Failed completely within 600 wheel trips.
[2] Extrapolated by extending displacement curve.

The test results indicated that, in general, a greater loss of stability took place in the mixtures in which water was added to the oiled aggregate than in those in which the water was added to the aggregate before the bitumen was applied. The results also corroborated the other test data which pointed to a definite superiority of the more viscous materials over those of low viscosity in resisting the effect of water.

In considering the results of the tests on wet mixtures it should be pointed out that the mineral filler used in these mixtures, while not an ideal filler material, was considerably better in quality than much of the soil that has often been used as filler in low-cost road surfaces. It is believed that had a clay filler containing more colloidal material been used, the detrimental effect of water on the mixtures tested would have been more striking.

TEST RESULTS ON WET MIXTURES SUMMARIZED

1. Although water in the mixtures caused cracking in the lean sections as well as in the rich ones, the lean mixtures showed very little loss of stability due to the addition of water while the richer mixtures showed a marked loss of stability from this cause.
2. Both dry and wet mixtures tested on wet bases lost stability more rapidly and were ultimately much less stable when the bitumen content was high than when it was low.
3. The rich mixtures did not absorb as much water from the wet bases as did the lean ones but this did not prevent their loss of stability since less additional liquid was required to affect them.
4. The mixtures containing bitumens of low viscosity lost stability more rapidly and to a greater degree, due to the action of water, than did those containing the heavier materials.
5. Cracking, pitting, and corrugating comprised the typical failures on the wet sections, and in addition, rutting occurred in the wet sections containing the higher percentages of bituminous material.
6. Surfaces that cracked while wet failed to heal after drying. The cracks persisted until the surfacing mixtures were broken up, remixed, and relaid.
7. Loss of stability occurred both in the wet mixtures on dry bases and in the mixtures that were tested on wet bases. However, while the former tended to dry out rapidly and regain their stability, the condition of the latter continued to grow steadily worse with the application of additional traffic.
8. Water added to the oiled aggregate mixtures caused, in general, a somewhat greater loss of stability than did water added to the aggregate before oiling. The reverse, however, was true of the wettest mixtures (those containing 6 percent of water).
9. The tests appear to justify the provision in numerous present-day specifications that limits the amount of moisture permitted in oil-processed surfacing mixtures to 2 percent at the time of laying. Such a provision seems desirable in order to insure against surface cracks which, once formed, fail to heal even after the moisture in the surface has evaporated.

INDEXES OF HIGHWAY CONSTRUCTION COSTS

REPORTED BY THE DIVISION OF MANAGEMENT, BUREAU OF PUBLIC ROADS

THE purchasing power of funds expended for highway construction, when expressed in miles of highway annually placed under construction, shows variations from year to year because of (1) actual variations in the cost of materials and labor entering into such construction, and (2) changes in design features, types, and quantities of materials actually used.

The effect of lowered prices of constituent units is immediately reflected in a downward trend in costs per mile whenever the quantities of materials used and labor required are subject to only minor variations. However, changing traffic conditions have required wider surfaces, longer sight distances, flatter curves, and other features conducive to safety with increased speed. Consequently, the effects of lower unit prices during recent years have been largely offset by the increased quantities of materials and excavation actually used, and average costs per mile have not fluctuated in accordance with fluctuations in the unit price of materials.

As a normal consequence of constantly increasing traffic on our highways, highway construction is continually undergoing changes, both in design and in materials used, and these changes have tended to complicate the development of simple index figures. To meet this condition three sets of index figures have been prepared.

1. A price trend index, based on the varying unit costs of a composite mile composed of the same quantities and materials for each year.
2. A usage trend index that shows the variations in quantities of excavation, surfacing, and structures actually placed in the composite mile constructed each year.
3. A cost trend index, that is based on the actual cost of the composite mile constructed each year.

Data for the Federal fiscal years 1925 to 1929 were taken as a basis for the calculations. The variations in price trend for the years 1922 to 1935 for the major components as well as for the composite mile are shown in figure 1.

Price, cost, and usage trend indexes are shown in figure 2 for the period 1923 to 1934. The effects of price and usage are combined to produce a cost trend for the composite mile. The cost trend follows a more uniform course than does either the usage or the price trend.

COST TREND OBTAINED BY COMBINING PRICE TREND AND USAGE TREND FOR COMPOSITE MILE OF HIGHWAY

The data covering materials, quantities, and unit costs were collected by the Bureau of Public Roads from the prices shown in the contracts awarded for road construction financed in whole or in part from Federal funds allotted to the States for construction on the Federal-aid highway system. Samples were taken from work financed wholly with State funds and it was found that Federal-aid and State projects were built to about the same standard.

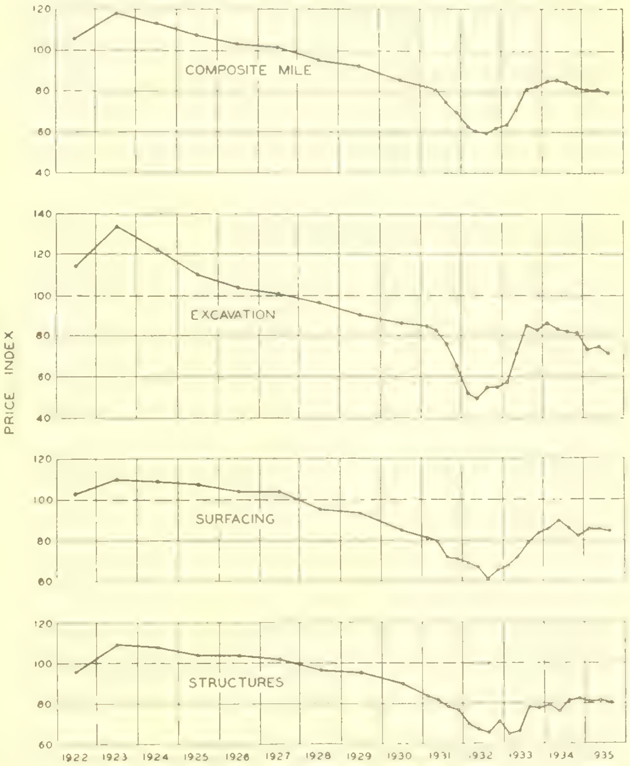


FIGURE 1.—PRICE TREND IN HIGHWAY CONSTRUCTION. AVERAGES FOR 1925 TO 1929 TAKEN AS A BASE.

Careful consideration of the available data led to the conclusion that a satisfactory usage index could be obtained if a composite mile of surfacing representative of the types of construction in Federal-aid and State annual programs were used. Accordingly, the component types of surfacing entering into the composite mile were taken from records of the combined highway mileages built annually, and the correlated items (grading, structural concrete, and steel) were based on the records available from construction with Federal funds. The propriety of the above procedure is assured by the fact that governing specifications are the same for both Federal-aid and wholly State construction, and that design and supervision of construction are performed by the State highway departments.

In building highways throughout the country the engineer must take into account wide differences in soils, availability and quality of materials, temperature, rainfall, traffic, and other factors, with a resulting wide range in construction practice. Many materials are important locally, but are of little significance to the country as a whole. Therefore, in the interest of simplifying reduction of data the following general items were selected as a basis for the indexes.

From Bureau of Public Roads records of bid prices:

Excavation—
- Common.
- Unclassified.
- Rock.

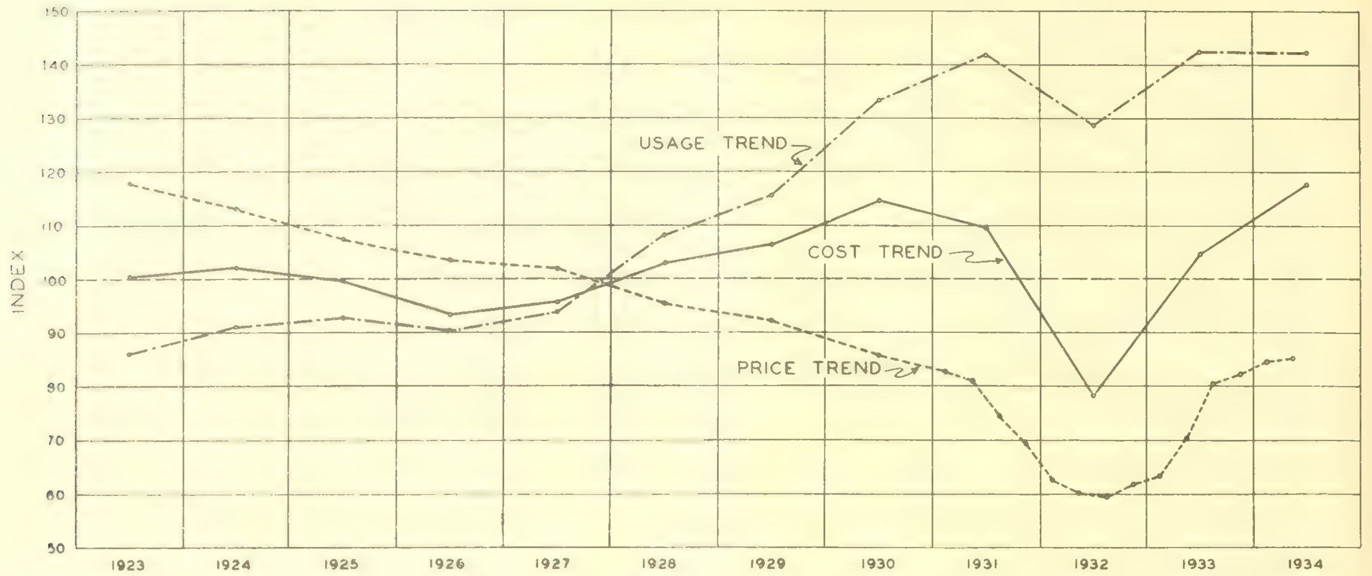


Figure 2.—Indexes of Highway Construction Cost. Averages for 1925 to 1929 Taken as a Base. Price Index Shows Trend in Cost of Composite Mile Composed of Same Quantities of Excavation, Surfacing, and Structures in Each Year. Usage Index Shows Trend in Quantities of Excavation, Surfacing, and Structures Used Per Mile in Each Year. Cost Index, Taking Account of Usage, Shows Trend in Actual Cost Per Mile.

Structures
- Reinforcing steel.
- Structural steel.
- Structural concrete, class A.
- Structural concrete, class B.
- Structural concrete, class C.

From records of mileage of State highways constructed:
- Gravel and sand-clay.
- Macadam.
- Bituminous macadam.
- Bituminous concrete.
- Portland-cement concrete.
- Brick.

These items cover somewhat more than 90 percent of the total cost of highway construction. Therefore, though their number is not great, they appear to be adequate. The items not used involve about the same basic commodities, manufacturing processes, transportation problems, and the same classes of labor that were involved in the items used. To include them would complicate the calculations but probably would neither clarify nor improve the result.

These representative items were accumulated and weighted, and further consolidated into three general groups—excavation, surfacing, and structures. The general group of excavation includes the three types of excavation, common, rock, and unclassified, and in addition includes the low-type surfaces such as topsoil, sand-clay, gravel, and treated and untreated macadam. These low-type surfaces have a low materials cost, generate little freight, and in construction methods and nature of equipment used are similar to grading operations, and so may be readily converted into the general group of excavation. In a similar manner the rigid types of surfacing have been converted into equivalent concrete pavement. Structures, which include bridges, culverts, railroad grade crossings, and safety devices, were reduced to three items: Reinforcing steel, structural steel, and structural concrete. The resulting final quantities per surfaced mile are shown in table 1.

Table 1.—*Final quantities per surfaced mile*

Year	Excavation				Surfacing					Structures		
	Excavation	Gravel [1]	Water-bound macadam [2]	Total excavation	Bituminous macadam	Bituminous concrete [3]	Brick [4]	Portland-cement concrete	Total surfacing	Reinforcing steel	Structural steel	Structural concrete
	Cubic yards	*Cubic yards*	*Cubic yards*	*Cubic yards*	*Square yards*	*Square yards*	*Square yards*	*Square yards*	*Square yards*	*Pounds*	*Pounds*	*Cubic yards*
1923	8,068	3,846	1,002	12,916	453	307	227	2,764	3,751	9,270	2,297	53
1924	8,364	3,792	1,237	13,393	391	351	137	2,960	3,839	12,374	2,258	67
1925	9,238	4,116	945	14,299	385	284	120	2,978	3,767	13,581	4,718	64
1926	11,068	4,695	837	16,600	405	215	103	2,452	3,175	14,070	3,629	68
1927	10,960	4,310	1,329	16,599	400	237	53	2,850	3,540	12,773	3,301	64
1928	12,545	4,050	757	17,352	692	273	86	3,297	4,348	17,075	4,953	65
1929	17,028	4,548	1,029	22,605	350	213	62	3,173	3,798	22,503	5,024	81
1930	18,946	4,426	797	24,169	345	247	92	3,640	4,324	26,852	7,750	122
1931	22,361	4,801	683	27,845	423	214	75	3,283	3,995	30,751	12,216	141
1932	18,423	4,874	692	23,989	429	218	76	3,332	4,055	29,243	10,807	102
1933	21,461	5,017	908	27,386	561	492	81	2,609	3,743	32,131	19,249	153
1934	28,270	6,163	684	35,117	515	508	42	1,360	2,425	29,963	21,733	158

[1] Includes sand-clay and topsoil.
[2] Includes treated and untreated macadam.
[3] Includes sheet asphalt.
[4] Includes all block pavements.

Base quantities and base prices (1925 to 1929) are shown in table 2. The base quantities and prices are the arithmetical averages of the quantities and prices by years for the base period.

TABLE 2.—*Average quantities and prices for the years 1925 to 1929, used as a base for computation of indexes*

Year	Excavation		Surfacing		Reinforcing steel		Structural steel		Structural concrete	
	Quantity	Price per cubic yard	Quantity	Price per square yard	Quantity	Price per pound	Quantity	Price per pound	Quantity	Price per cubic yard
	Cu. yd.		*Sq. yd.*		*Lb.*		*Lb.*		*Cu. yd.*	
1925	14,299	$0.386	3,767	$2.360	13,581	$0.0565	4,718	$0.0667	64	$22.534
1926	16,600	.364	3,175	2.286	14,070	.0534	3,629	.0738	68	22.760
1927	16,599	.352	3,540	2.291	12,773	.0510	3,301	.0705	64	22.647
1928	17,352	.337	4,348	2.096	17,075	.0492	4,953	.0671	65	21.216
1929	22,605	.316	3,798	2.055	22,503	.0481	5,024	.0591	81	21.582
Total	87,455	1.755	18,628	11.088	80,002	.2582	21,625	.3372	342	110.739
Average	17,491	.351	3,726	2.218	16,000	.0516	4,325	.0674	68	22.148

The price index.—The method of computing the price index is shown in table 3. The composite mile on which the price index is based is composed of the average quantities of excavation, surfacing, and structures as determined for the base period 1925 to 1929. The average bid price for each of these items is shown for the years 1922 to 1935. The figures given in the amount columns are the costs of the average quantities at the prevailing rate for the year or quarter. The index figures give a comparison between the year or quarter and the base period 1925 to 1929. The results given in this table are shown in graphical form in figure 1.

The usage index.—The usage index shows the effect of changing practices in design features and use of materials in the highway-construction field. It is obtained by applying the average prices as determined for the base period to the various quantities of the base items used. The result shows how the cost would have varied because of changing usage had the unit prices remained constant. These changes in construction practices are shown in tabular form in table 4, and graphically by the usage trend in figure 2.

The cost index.—The cost index is obtained by combining the average annual quantities used, as shown in table 4, with the average annual unit prices that they cost. This index is shown in tabular form in table 5 and graphically by the cost trend in figure 2.

TABLE 3.—*Price trend in highway construction*

Year	Excavation (17,491 cubic yards)[1]			Surfacing (3,726 square yards)[2]			Structures								Composite mile	
							Reinforcing steel (16,000 pounds)		Structural steel (4,325 pounds)		Structural concrete (68 cubic yards)		Combined			
	Bid price	Amount	Sub-index	Bid price	Amount	Sub-index	Bid price	Amount	Bid price[3]	Amount	Bid price	Amount	Amount	Sub-index	Total amount	Index
Base period, 1925 to 1929	$0.35	$6,139	100.0	$2.22	$8,264	100.0	$0.052	$826	$0.067	$291	$22.15	$1,506	$2,623	100.0	$17,026	100.0
1922	.40	7,031	114.5	2.28	8,488	102.7	.050	800	.074	321	20.18	1,372	2,493	95.1	18,012	105.8
1923	.47	8,186	133.3	2.43	9,047	109.5	.057	920	.078	338	23.37	1,589	2,847	108.6	20,080	117.9
1924	.43	7,504	122.2	2.40	8,950	108.3	.057	920	.077	333	22.91	1,558	2,811	107.2	19,265	113.1
1925	.39	6,751	110.0	2.36	8,793	106.4	.056	904	.067	288	22.53	1,532	2,724	103.9	18,268	107.3
1926	.36	6,367	103.7	2.29	8,518	103.1	.053	854	.074	318	22.76	1,548	2,720	103.7	17,605	103.4
1927	.35	6,157	100.3	2.29	8,536	103.3	.051	816	.071	306	22.65	1,540	2,662	101.5	17,355	101.9
1928	.34	5,894	96.0	2.10	7,810	94.5	.049	787	.067	290	21.22	1,443	2,520	96.1	16,224	95.3
1929	.32	5,527	90.0	2.05	7,657	92.7	.048	770	.059	256	21.58	1,468	2,494	95.0	15,678	92.1
1930	.30	5,300	86.3	1.86	6,949	84.1	.045	715	.061	264	20.08	1,365	2,344	89.4	14,593	85.7
1931																
First quarter	.30	5,195	84.6	1.79	6,666	80.7	.042	672	.055	240	18.90	1,285	2,197	83.7	14,058	82.6
Second quarter	.29	5,072	82.6	1.77	6,580	79.6	.041	658	.051	219	18.48	1,257	2,134	81.3	13,786	81.0
Third quarter	.27	4,705	76.6	1.59	5,924	71.7	.040	634	.052	224	17.49	1,189	2,047	78.0	12,676	74.4
Fourth quarter	.23	3,988	65.0	1.56	5,809	70.3	.037	594	.056	244	17.22	1,171	2,009	76.6	11,806	69.3
1932																
First quarter	.18	3,166	51.6	1.52	5,656	68.4	.036	571	.049	211	15.22	1,035	1,817	69.3	10,639	62.5
Second quarter	.17	2,991	48.7	1.47	5,481	66.3	.034	538	.045	197	14.98	1,019	1,754	66.8	10,226	60.1
Third quarter	.19	3,358	54.7	1.35	5,045	61.0	.033	526	.043	184	14.82	1,008	1,718	65.5	10,121	59.4
Fourth quarter	.19	3,323	54.1	1.41	5,377	65.1	.033	528	.048	208	16.28	1,107	1,843	70.3	10,543	61.9
1933																
First quarter	.20	3,498	57.0	1.49	5,552	67.2	.032	506	.043	187	15.44	1,050	1,743	66.4	10,793	63.4
Second quarter	.25	4,338	70.7	1.58	5,894	71.3	.035	552	.043	188	14.67	997	1,737	66.2	11,969	70.3
Third quarter	.30	5,194	84.6	1.74	6,498	78.6	.041	657	.049	212	17.36	1,180	2,049	78.1	13,741	80.7
Fourth quarter	.29	5,054	82.3	1.85	6,904	83.5	.042	669	.049	212	17.12	1,163	2,044	77.9	14,002	82.2
1934																
First quarter	.30	5,247	85.5	1.90	7,079	85.7	.042	672	.049	212	17.82	1,212	2,096	79.9	14,422	84.7
Second quarter	.29	5,072	82.6	1.98	7,377	89.3	.042	678	.051	221	17.31	1,177	2,076	79.1	14,525	85.3
Third quarter	.29	5,016	81.7	1.92	7,161	86.7	.042	680	.053	231	17.98	1,222	2,133	81.3	14,310	84.0
Fourth quarter	.29	4,988	81.3	1.82	6,781	82.1	.044	712	.057	245	17.81	1,211	2,168	82.7	13,937	81.9
1935																
First quarter	.25	4,460	72.7	1.90	7,091	85.8	.044	699	.051	219	17.62	1,198	2,116	80.7	13,667	80.3
Second quarter	.26	4,548	74.1	1.89	7,031	85.1	.044	712	.052	225	17.51	1,191	2,128	81.1	13,707	80.5
Third quarter	.25	4,355	70.9	1.88	7,009	84.8	.044	709	.052	224	17.22	1,171	2,104	80.2	13,468	79.1

[1] Common excavation plus other excavation items expressed as equivalent common excavation.

[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete

[3] Indexes and totals were calculated with the bid prices carried to 1 more decimal place than that to which they are shown in the table

TABLE 4.—*Usage trend in highway construction*

Year	Excavation [1] ($0.351 per cubic yard)			Surfacing [2] ($2.218 per square yard)			Structures								Composite mile	
							Reinforcing steel ($0.0516 per pound)		Structural steel ($0.0674 per pound)		Structural concrete ($22.148 per cubic yard)		Combined			
	Quantity	Amount	Subindex	Quantity	Amount	Subindex	Quantity	Amount	Quantity	Amount	Quantity	Amount	Amount	Subindex	Total amount	Index
	Cubic yards			*Square yards*			*Pounds*		*Pounds*		*Cubic yards*					
Base period, 1925 to 1929	17,491	$6,139	100.0	3,726	$8,264	100.0	16,000	$826	4,325	$291	68	$1,506	$2,623	100.0	$17,026	100.0
1923	12,916	4,533	73.8	3,751	8,320	100.7	9,270	478	2,297	155	53	1,174	1,807	68.9	14,660	86.1
1924	13,393	4,701	76.6	3,839	8,515	103.0	12,374	638	2,258	152	67	1,484	2,274	86.7	15,490	91.0
1925	14,299	5,019	81.7	3,767	8,355	101.1	13,581	701	4,718	318	64	1,417	2,436	92.9	15,810	92.9
1926	16,600	5,827	94.9	3,175	7,042	85.2	14,070	726	3,629	245	68	1,506	2,477	94.4	15,346	90.1
1927	16,599	5,826	94.9	3,540	7,852	95.0	12,773	659	3,301	222	64	1,417	2,298	87.6	15,976	93.8
1928	17,352	6,091	99.2	4,348	9,644	116.7	17,075	881	4,953	334	65	1,440	2,655	101.2	18,390	108.0
1929	22,605	7,934	129.2	3,798	8,424	101.9	22,503	1,161	5,024	339	81	1,794	3,294	125.6	19,652	115.4
1930	24,169	8,483	138.2	4,324	9,591	116.0	26,852	1,386	7,750	522	122	2,702	4,610	175.7	22,684	133.2
1931	27,845	9,774	159.2	3,995	8,861	107.2	30,751	1,587	12,216	823	141	3,123	5,533	210.9	24,168	141.9
1932	23,989	8,420	137.2	4,055	8,994	108.8	29,243	1,509	10,807	728	102	2,259	4,496	171.4	21,910	128.7
1933	27,386	9,612	156.6	3,743	8,302	100.5	32,131	1,658	19,249	1,297	153	3,389	6,344	241.9	24,258	142.5
1934	35,117	12,326	200.8	2,425	5,379	65.1	29,963	1,546	21,733	1,465	158	3,499	6,510	248.2	24,215	142.2

[1] Common excavation plus other excavation items expressed as equivalent common excavation.
[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete.

TABLE 5.—*Cost trend in highway construction*

Year	Excavation [1]				Surfacing [2]				Structures												Composite mile	
									Reinforcing steel			Structural steel			Structural concrete			Combined			
	Bid price	Quantity	Amount	Subindex	Bid price [3]	Quantity	Amount	Subindex	Bid price [3]	Quantity	Amount	Bid price [3]	Quantity	Amount	Bid price [3]	Quantity	Amount	Amount	Subindex	Amount	Index
		Cubic yards				*Square yards*				*Pounds*			*Pounds*			*Cubic yards*					
Base period, 1925 to 1929	$0.35	17,491	$6,139	100.0	$2.22	3,726	$8,264	100.0	$0.052	16,000	$826	$0.067	4,325	$291	$22.15	68	$1,506	$2,623	100.0	$17,026	100.0
1923	.47	12,916	6,045	98.5	2.43	3,751	9,107	110.2	.057	9,270	533	.078	2,297	180	23.37	53	1,239	1,952	74.4	17,104	100.5
1924	.43	13,393	5,746	93.6	2.40	3,839	9,221	111.6	.057	12,374	711	.077	2,258	174	22.91	67	1,535	2,420	92.3	17,387	102.1
1925	.39	14,299	5,519	89.9	2.36	3,767	8,890	107.6	.056	13,581	767	.067	4,718	315	22.53	64	1,442	2,524	96.2	16,933	99.5
1926	.36	16,600	6,042	98.4	2.29	3,175	7,258	87.8	.053	14,070	751	.074	3,629	267	22.76	68	1,548	2,566	97.8	15,866	93.2
1927	.35	16,599	5,843	95.2	2.29	3,540	8,110	98.1	.051	12,773	651	.071	3,301	233	22.65	64	1,449	2,333	89.0	16,286	95.7
1928	.34	17,352	5,848	95.2	2.10	4,348	9,113	110.3	.049	17,075	840	.067	4,953	332	21.22	65	1,379	2,551	97.3	17,512	102.9
1929	.32	22,605	7,143	116.4	2.05	3,798	7,805	94.4	.048	22,503	1,082	.059	5,024	297	21.58	81	1,748	3,127	119.2	18,075	106.2
1930	.30	24,169	7,323	119.3	1.86	4,324	8,064	97.6	.045	26,852	1,200	.061	7,750	473	20.08	122	2,449	4,122	157.2	19,509	114.6
1931	.27	27,845	7,546	122.9	1.68	3,995	6,696	81.0	.040	30,751	1,227	.054	12,216	655	18.02	141	2,541	4,423	168.6	18,665	109.6
1932	.18	23,989	4,378	71.3	1.44	4,055	5,859	70.9	.034	29,243	994	.046	10,807	499	15.32	102	1,563	3,056	116.5	13,293	78.1
1933	.26	27,386	7,066	115.1	1.67	3,743	6,240	75.5	.037	32,131	1,195	.046	19,249	889	16.15	153	2,470	4,554	173.6	17,860	104.9
1934	.29	35,117	10,184	165.9	1.91	2,425	4,622	55.9	.043	29,963	1,285	.052	21,733	1,139	17.73	158	2,801	5,225	199.2	20,031	117.6

[1] Common excavation plus other excavation items expressed as equivalent common excavation.
[2] Portland-cement concrete plus other surfacing items expressed as equivalent portland-cement concrete.
[3] Indexes and totals were calculated with the bid prices carried to 1 more decimal place than that to which they are shown in this table.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936 FUNDS

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 2,604,320										$ 2,604,320
Arizona	1,781,347	$ 893,900	$ 675,911	59.2	$ 1,093,138	$ 921,221	42.3	$ 50,012	$ 19,640		164,575
Arkansas	2,142,723										2,142,723
California	4,756,959	564,411	326,307	9.5	4,957,583	2,834,811	116.3	2,602,530	1,496,657	62.1	99,184
Colorado	2,288,811	754,247	421,857	31.5	1,712,848	955,075	62.7	610,633	341,955	18.3	569,924
Connecticut	791,253				780,030	387,812	8.0	323,789	156,539	7.0	246,901
Delaware	609,375				439,748	219,874	34.4				389,501
Florida	1,655,723				831,120	415,560	27.5	268,640	134,320	8.7	1,105,843
Georgia	3,168,221				979,489	459,220	74.6	1,738,650	869,325	91.7	1,839,676
Idaho	1,531,162	351,681	199,729	60.4	1,535,349	916,660	111.9	283,672	162,749	16.4	252,024
Illinois	5,160,696	158,176	79,088	2.5	6,483,725	3,239,507	101.5	2,462,479	1,194,240	41.8	647,861
Indiana	3,087,613	845,419	421,740	29.5	4,772,580	2,386,205	167.9	241,094	120,510	4.9	159,158
Iowa	3,231,718	284,024	134,060	62.8	5,858,636	2,757,665	245.0	706,247	332,340	131.0	7,653
Kansas	3,317,054	208,591	104,295	187.2	2,751,463	1,375,732	172.7	4,085,702	1,825,518	478.4	11,509
Kentucky	2,304,143	667,119	330,805	42.6	1,495,589	732,800	99.1	1,450,355	690,897	37.7	549,641
Louisiana	1,776,939	214,279	107,140	7.3	1,957,491	978,745	68.7	1,018,497	509,249	31.6	181,805
Maine	1,090,167	211,352	105,676	4.3	1,500,980	750,490	49.3	191,524	95,762	4.1	138,239
Maryland	1,025,870										1,025,870
Massachusetts	1,741,877				333,935	166,968	3.1				1,574,909
Michigan	3,837,292	1,115,385	556,196	36.0	4,877,868	2,436,209	187.4	1,302,800	651,400	44.0	193,488
Minnesota	3,423,306	526,449	239,815	47.4	5,068,032	2,312,407	355.8	1,590,477	756,927	69.5	114,157
Mississippi	2,196,524										2,196,524
Missouri	3,800,856	1,100,172	549,003	221.2	3,203,835	1,601,917	136.8	2,849,812	1,424,819	88.6	225,117
Montana	2,560,449	743,868	416,359	142.1	3,032,832	1,698,032	204.5	707,263	395,997	79.5	50,011
Nebraska	2,581,663	1,098,358	549,099	66.5	1,115,073	576,899	127.1	929,663	464,832	127.7	990,833
Nevada	1,595,501	609,275	526,163	98.8	669,232	579,353	75.7	31,657	27,405	20.9	462,580
New Hampshire	609,375				748,375	367,840	22.2	141,629	70,736	1.9	170,799
New Jersey	1,675,751	87,925	43,962	1.0	2,030,222	1,015,111	28.9	1,321,388	574,164	10.4	42,514
New Mexico	1,999,299	583,962	355,094	62.3	2,129,748	1,295,312	121.7	542,230	339,164	18.8	9,729
New York	6,150,106	55,200	27,600	.1	10,633,475	5,258,735	191.8	1,113,955	556,977	9.4	306,794
North Carolina	2,938,657	197,121	98,561	37.1	1,674,113	834,591	236.8	1,939,522	953,203	193.3	1,052,302
North Dakota	1,960,162				187,005	101,941	.1				1,858,221
Ohio	4,565,435				4,760,772	2,315,087	65.2	2,301,792	1,020,808	24.1	1,229,540
Oklahoma	2,947,521	513,155	269,663	20.5	1,534,453	804,100	46.8	815,264	428,421	30.0	1,445,337
Oregon	2,044,633	341,519	206,184	14.4	2,993,539	1,744,551	91.5	122,949	66,767	4.4	27,131
Pennsylvania	5,348,062	100,109	49,786	2.2	6,767,002	3,383,501	99.9	1,447,456	722,532	19.9	1,192,243
Rhode Island	609,375										609,375
South Carolina	1,692,896				50,787	25,394		34,891	15,701	8.7	1,651,802
South Dakota	2,036,775				951,492	550,920	99.8	300,996	164,921	49.5	1,320,934
Tennessee	2,638,159	305,225	152,612	13.3	1,277,334	638,667	52.2	159,522	79,761	7.2	1,767,119
Texas	7,777,504	3,356,934	1,675,503	173.7	7,155,119	3,571,796	402.5	3,869,374	1,840,622	164.6	689,583
Utah	1,410,752	270,910	190,263	17.9	1,452,365	1,045,437	98.4	67,763	48,924	3.1	126,127
Vermont	609,375	22,052	10,786	2.9	1,159,127	579,564	54.1	28,646	14,286	2.4	4,739
Virginia	2,278,475	29,837	14,919	1.6	2,004,441	1,002,220	81.9	802,846	401,423	25.3	859,913
Washington	1,949,957	741,249	389,587	21.4	2,124,427	1,118,049	65.2	361,438	190,200	27.2	252,121
West Virginia	1,356,793	87,161	43,581	3.0	791,269	395,622	36.5	389,386	194,693	10.2	722,897
Wisconsin	3,045,557	511,344	255,672	18.9	2,379,194	1,187,004	86.7	2,554,529	1,248,665	91.9	354,216
Wyoming	1,559,444	952,899	586,437	110.9	1,573,069	948,306	163.7				24,701
District of Columbia											
Hawaii	609,375				267,058	131,547	3.5	177,989	88,565	4.6	389,263
TOTALS	121,875,000	18,503,308	10,113,453	1,615.0	110,094,962	57,018,507	4,521.7	41,939,061	20,691,614	2,070.8	34,051,426

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,067,503	$ 3,067,503	97.5	$ 560,971	$ 560,971	13.3	$ 522,640
Arizona	2,569,841	$ 700,390	$ 696,320	42.2	2,006,231	1,467,044	138.8	148,266	64,975	4.0	341,503
Arkansas	3,352,061	88,135	88,135	10.8	2,118,192	2,114,286	189.4	981,190	968,207	136.1	181,433
California	7,747,928	325,910	292,005	33.6	5,671,241	5,506,521	184.8	777,450	760,355	17.1	1,189,047
Colorado	3,395,263	408,119	408,119	33.5	1,378,555	1,378,164	52.0	58,855	58,855	2.5	1,550,125
Connecticut	1,418,709				274,047	252,390		82,024	81,225	.2	1,085,095
Delaware	900,310				445,795	445,795	39.6	93,390	93,390	19.3	361,125
Florida	2,597,144				2,001,384	1,983,511	72.3	284,788	284,788	11.2	328,844
Georgia	4,988,967	49,637	49,637	.7	383,705	383,705	28.3	303,348	303,348	19.3	4,252,277
Idaho	2,222,747	31,808	31,087	3.6	1,378,842	1,376,921	110.8	647,270	511,036	54.1	303,703
Illinois	8,694,009	241,980	241,980	9.2	6,127,765	6,127,765	313.6	1,498,420	1,498,420	125.1	825,844
Indiana	4,941,255	76,586	76,586	2.6	3,429,048	3,429,048	192.7	1,390,985	1,390,985	37.8	44,637
Iowa	4,991,664	63,000	59,100	30.1	2,451,695	2,329,915	225.4	1,010,633	956,900	103.9	1,645,749
Kansas	4,994,975	62,909	62,909	31.1	2,929,181	2,929,181	246.7	1,672,454	1,671,968	88.7	330,916
Kentucky	3,726,271	29,105	29,105	4.0	1,778,322	1,778,322	242.5	1,058,690	1,052,223	80.3	866,620
Louisiana	2,890,429				744,115	594,896	39.1	1,975,647	1,781,166	132.0	514,367
Maine	1,676,799	8,269	8,269	.5	1,009,106	1,008,558	43.9	567,443	567,443	25.0	92,529
Maryland	1,750,738				172,131	172,131	9.7	945,049	821,579	26.6	757,028
Massachusetts	3,262,885				117,754	117,754	1.1	71,042	71,042	1.4	3,074,089
Michigan	6,301,414	449,100	449,100	25.4	5,436,171	5,376,141	248.1	291,000	291,000	10.8	185,173
Minnesota	5,277,145	208,442	205,834	56.7	2,959,419	2,664,661	390.8	1,866,911	1,532,680	382.2	873,970
Mississippi	3,457,552	58,669	58,669	2.8	2,475,738	2,472,645	166.8	601,542	601,542	38.4	324,697
Missouri	6,012,652	382,553	382,553	180.1	3,280,826	3,280,590	485.8	1,691,627	1,689,526	117.0	659,984
Montana	3,676,416	194,813	194,813	9.4	3,078,597	3,078,597	169.1	356,657	356,657	7.0	46,349
Nebraska	3,870,739	7,994	7,994	.7	2,272,520	2,231,595	248.2	743,385	743,385	70.5	887,764
Nevada	2,243,074	669,447	652,447	24.1	941,539	918,969	40.7	76,563	76,563	9.8	595,095
New Hampshire	945,225				335,781	322,876	9.9	190,605	182,292	14.9	440,057
New Jersey	3,129,805				2,014,617	2,014,617	12.9	160,336	160,336	5.5	954,851
New Mexico	2,871,397	341,527	341,527	41.7	1,638,322	1,638,322	97.1	408,575	408,575	37.3	482,974
New York	11,046,377				9,311,728	8,899,928	127.3	1,174,660	1,174,660	33.2	971,789
North Carolina	4,720,173	183,120	183,120	20.8	2,587,629	2,555,040	182.3	710,835	626,320	29.3	1,355,693
North Dakota	2,867,245	162,637	162,637	20.8	505,899	505,899	64.6	1,355,255	1,355,255	162.1	843,455
Ohio	7,670,815	15,590	15,590	.3	3,895,734	3,831,134	43.6	988,555	940,181	94.6	2,883,909
Oklahoma	4,580,670	53,431	53,431	6.4	1,610,793	1,608,466	132.5	1,889,159	1,889,072	222.2	1,029,700
Oregon	3,038,642				2,205,493	2,193,484	93.2	620,647	537,339	68.7	307,819
Pennsylvania	9,347,797	35,092	35,092	2.4	1,093,587	1,031,928	33.3	1,361,332	1,357,294	73.4	6,923,483
Rhode Island	989,208	15,934	15,934		962,220	962,220	18.9	9,192	9,192	.2	1,863
South Carolina	2,702,012	47,193	47,193	2.4	798,132	765,650	79.7	1,210,780	1,205,363	109.2	683,806
South Dakota	2,976,454	152,013	152,013	88.1	1,258,006	1,257,976	228.3	554,190	554,190	70.1	1,012,275
Tennessee	4,192,460				1,660,053	1,660,053	67.7	1,158,796	1,158,796	46.8	1,373,611
Texas	11,989,350	860,755	766,946	96.0	9,576,366	8,800,302	818.3	2,191,588	2,049,531	187.6	372,571
Utah	2,067,154	163,709	163,543	9.8	991,883	976,551	86.8	434,574	385,086	39.1	541,974
Vermont	924,306	19,129	17,054	.2	648,118	572,492	13.4	348,659	316,794	9.1	17,966
Virginia	3,652,667	194,006	193,517	131.1	2,013,736	1,992,606	717.1	702,020	692,908	150.4	773,636
Washington	3,026,161	82,914	81,917	9.2	2,541,851	2,289,704	130.0	294,793	277,164	7.3	377,376
West Virginia	2,231,412				1,201,948	1,201,948	46.4	436,104	435,812	19.2	593,652
Wisconsin	4,823,884	113,268	103,038	4.1	3,506,289	3,163,135	205.4	1,750,130	1,556,956	120.3	755
Wyoming	2,219,155				1,748,480	1,748,465	103.2	233,673	233,668	26.0	237,022
District of Columbia	949,496	520,241	520,241	4.0	487,235	428,229	4.5				1,026
Hawaii	926,033				636,394	615,298	8.9				310,735
TOTALS	195,000,000	7,017,425	6,847,455	938.4	111,159,716	107,522,931	7,303.0	37,940,058	36,297,013	3,060.1	44,332,601

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CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF MAY 31, 1936

STATE	APPORTIONMENT	COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		Estimated Total Cost	Works Program Funds	NUMBER		
				Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signals or Otherwise			Eliminated by Separation or Relocation	Protected By Signal or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1		$ 2,825,809	$ 2,825,809	27		$ 914,123	$ 914,123	9	5	$ 285,561
Arizona	1,256,099	47,412	47,412	1		951,552	823,340	9		124,309	106,387	1		278,960
Arkansas	3,574,060	191,070	190,975	4		1,013,452	1,009,839	23		1,326,136	1,323,317	24		1,049,930
California	7,486,362	22,330	22,330	1		6,108,326	5,864,147	35		1,330,681	1,326,739	21		273,147
Colorado	2,631,567					1,266,543	1,245,543	20		128,712	128,712	1		1,257,312
Connecticut	1,712,684													1,712,684
Delaware	418,239									143,486	120,000	1		298,239
Florida	2,827,883					1,476,880	1,474,569	13		387,794	387,794	4		965,519
Georgia	4,895,949					10,581	10,581			344,859	344,859	5		4,540,510
Idaho	1,674,479					852,091	852,091	12		121,445	108,758	2		713,630
Illinois	10,307,184					4,092,637	4,092,637	38		2,166,583	2,166,583	18		4,047,964
Indiana	5,111,096					2,222,383	2,222,383	19		2,288,562	2,288,562	12		600,151
Iowa	5,600,679	7,303	7,000	1		1,914,133	1,830,250	41		1,097,787	1,053,050	27		2,710,379
Kansas	5,246,258					2,517,667	2,517,667	28		2,770,181	2,728,591	30		
Kentucky	3,672,387					985,363	985,363	13		1,536,334	1,246,602	8		1,440,422
Louisiana	3,213,467					234,295	228,587	2		2,225,485	1,886,728	20		1,098,152
Maine	1,426,861					424,611	424,278	8		547,419	546,724	10		455,859
Maryland	2,061,751					292,968	292,968	3		639,813	617 344	4		1,151,439
Massachusetts	4,210,833					956,239	956,239	6		541,921	541 921	6		2,712,674
Michigan	6,765,197	121,850	121,850	1		4,973,252	4,973,252	37		820,350	820,350	9		849,745
Minnesota	5,395,441	21,950	21,950	1		1,742,914	1,736,864	38	1	1,066,234	1,066,234	19	8	2,570,393
Mississippi	3,241,475					1,582,321	1,582,321	34		412,052	412,052	8	1	1,247,102
Missouri	6,142,153					2,948,063	2,948,063	20		2,094,576	2,081,308	13		1,112,781
Montana	2,722,327					2,515,850	2,515,850	38		84,926	84,926	1		121,551
Nebraska	3,556,441					1,598,882	1,598,882	49		517,112	517,112	17		1,440,447
Nevada	887,260	86,337	86,337	2		621,949	621,949	8						178,974
New Hampshire	822,484					372,387	372,387	3		13,154	13,154		1	436,943
New Jersey	3,983,826					949,148	949,148	5		306,130	306,130	2		2,728,549
New Mexico	1,725,286	180,565	180,565	4		856,642	844,470	5						700,251
New York	13,577,189					7,069,964	6,809,418	22		2,632,090	2,631,810	8		4,135,961
North Carolina	4,823,958	10,268	10,268	1		1,211,295	1,211,295	14		835,468	835,468	12		2,766,926
North Dakota	3,207,473					396,659	396,659	9		413,748	413,748	15		2,397,066
Ohio	8,439,897					652,998	652,998	3		1,627,500	1,531,761	13		6,255,137
Oklahoma	5,004,711	12,408	12,408	1		1,406,310	1,406,310	27		1,029,266	1,029,266	15		2,556,727
Oregon	2,334,204					1,405,993	1,405,454	12		948,320	824,147	8		104,603
Pennsylvania	11,483,613					1,499,280	1,410,874	21		2,830,655	2,804,148	20		7,268,590
Rhode Island	699,691					654,008	654,008	4						45,683
South Carolina	3,059,956					1,074,270	1,067,966	22		317,409	317,095	9		1,674,895
South Dakota	3,249,086	51,774	51,774	1		707,011	707,011	14		141,286	141,286	8		2,349,016
Tennessee	3,903,979					365,701	365,701	9		363,383	363,383	10	7	3,174,895
Texas	10,855,982	34,420	34,420	2		4,511,049	4,319,574	55		3,766,712	3,495,834	47		3,006,154
Utah	1,230,763					462,506	462,506	6		279,548	259,448	3		508,809
Vermont	729,857					462,011	460,653	7		45,881	45,881	2		223,323
Virginia	3,774,287					1,090,993	1,020,129	20		621,997	621,997	24	7	2,132,161
Washington	3,095,041					1,722,370	1,717,570	19	1	310,628	310,597	7	6	1,066,874
West Virginia	2,677,937					108,323	108,323	1		659,969	659,969	5		1,909,645
Wisconsin	5,022,683	69,151	69,151	1		2,269,144	2,260,266	21		623,271	623,271	6		2,069,994
Wyoming	1,360,841	55,366	55,365	2		220,743	220,742	2		117,278	117,277	1		967,457
District of Columbia	410,804					170,643	170,643	2		253,264	238,616	1		1,545
Hawaii	453,703					296,218	295,333	3		215,430	158,369	2		1
TOTALS	196,000,000	921,328	920,929	24		74,064,427	72,922,910	827	2	41,983,267	40,561,431	488	35	81,594,730

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF MAY 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Funds)	Act of June 18, 1934 (1935 Funds)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,378,614	$ 8,187,466	$ 2,816,248	736.2	$ 1,069,841	$ 160,296	$ 909,545	38.6		$ 479,385	2.9	$ 22,371	$ 54,664
Arizona	5,211,960	2,641,935	8,895,859	5,203,929	2,538,279	545.2	111,719		62,276	1.1				8,031	41,380
Arkansas	6,748,335	3,428,049	10,626,310	6,664,012	3,093,133	600.3	306,294	63,188	224,593	18.0	$ 21,152	63,198	2.3	99,983	47,124
California	15,607,354	7,932,206	28,560,858	15,589,248	6,928,687	741.4	2,064,841		953,278	19.0		820		18,105	49,421
Colorado	6,874,530	3,486,006	11,156,172	6,831,431	3,438,848	636.3	6,817		6,500					43,099	40,658
Connecticut	2,865,740	1,454,868	4,061,007	2,790,584	857,758	69.2	482,548		453,705	4.7				75,156	143,406
Delaware	1,819,088	923,395	2,643,857	1,819,088	782,660	128.3	88,530		88,530	.5		52,205	1.1		
Florida	5,231,834	2,661,343	8,485,965	5,187,944	1,994,276	294.9	562,346		526,291	14.0		55,876	.8	43,890	84,900
Georgia	10,091,185	5,113,491	11,958,542	9,128,958	2,335,866	678.0	1,434,362	379,753	1,006,585	69.8	384,612	665,507	73.4	197,862	1,105,733
Idaho	4,486,249	2,277,486	6,541,524	4,416,568	1,709,392	494.5	508,659		506,879	7.0	42,905	12,377		26,776	48,838
Illinois	17,570,770	8,921,401	22,493,796	16,147,212	5,597,651	623.6	4,586,193	1,274,335	2,992,129	71.2	3,837	19,238		144,785	312,383
Indiana	10,037,843	5,088,963	13,362,272	9,629,709	3,115,809	409.7	2,281,764	388,697	1,809,942	80.6		134,587	.4	19,437	28,626
Iowa	10,055,660	5,118,361	15,342,129	10,055,660	4,681,685	1,215.6	197,598		181,041	3.6		226,800	5.0		28,835
Kansas	10,089,604	5,117,675	15,149,328	9,932,696	4,857,804	1,115.8	387,954	107,706	245,161	17.7	5,871	5,140	.9	43,330	9,570
Kentucky	7,517,359	3,818,311	10,980,706	7,018,377	3,166,976	789.2	829,443	421,471	355,382	16.8	29,243	179,995	5.7	48,269	115,957
Louisiana	5,828,591	2,963,932	8,586,134	5,617,484	2,349,072	230.1	492,944	138,621	354,323	20.5	53,784	72,999	6.4	18,702	187,538
Maine	3,369,917	1,711,586	5,096,627	3,337,543	1,541,314	191.6	108,297		108,283	1.4				32,374	61,989
Maryland	3,564,527	1,810,058	4,473,059	2,899,421	624,669	114.5	1,081,343	552,686	516,805	36.5	30,000	222,668	9.1	82,420	445,916
Massachusetts	6,597,100	3,350,474	7,105,806	4,599,679	1,870,151	104.3	3,073,307	1,896,850	1,176,457	11.0		22,836		100,570	281,031
Michigan	12,736,227	6,452,568	18,695,878	12,538,651	4,816,677	682.6	1,790,175	163,400	1,568,797	85.7		30,825	.1	34,176	36,268
Minnesota	10,656,569	5,425,551	15,386,093	9,866,602	4,700,167	1,624.5	932,911	656,932	237,274	20.7	3,168	152,808	.6	129,867	335,302
Mississippi	6,978,675	3,540,227	11,624,100	6,557,815	2,221,201	664.2	1,624,012	330,980	1,224,067	79.7	6,555	51,836	1.3	83,325	43,123
Missouri	12,180,306	6,173,740	16,634,942	11,175,592	4,390,472	1,405.5	2,848,117	901,729	1,686,146	45.8		92,597	.4	102,985	4,525
Montana	7,439,748	3,769,734	10,975,765	7,173,669	3,138,022	1,005.2	668,314	159,632	492,278	27.4	57,745	98,365	20.2	48,703	41,069
Nebraska	7,828,961	3,964,364	12,435,684	7,725,872	3,432,884	995.4	781,732	65,535	506,111	42.4		11,397		37,555	13,972
Nevada	4,545,917	2,302,356	6,753,604	4,484,176	1,988,495	741.9	298,776	26,150	272,626	11.9		11,490	.7	35,591	29,746
New Hampshire	1,909,839	969,462	2,956,960	1,904,951	920,975	77.3	16,872		16,610	.4				4,889	31,877
New Jersey	6,346,039	3,220,879	7,073,060	5,986,387	727,336	76.7	2,485,327	175,941	1,992,453	10.6		303,276	6.6	183,711	197,814
New Mexico	5,792,935	2,941,700	8,514,329	5,624,747	2,667,109	761.6	186,670		175,678	2.0		8,561		168,189	90,352
New York	22,330,101	11,327,921	37,149,021	21,500,277	9,130,852	800.7	3,346,835	633,597	2,070,045	22.5	85,734	67,420	.7	110,493	59,604
North Carolina	9,522,293	4,840,941	14,391,598	9,044,715	4,125,439	1,325.0	515,195	75,589	427,711	16.1	179,281	205,439	13.5	222,709	82,352
North Dakota	5,804,448	2,938,967	7,324,784	5,436,458	1,227,275	1,959.7	1,034,194	181,402	772,738	133.0	17,146	377,958	47.6	169,442	560,995
Ohio	15,484,592	7,865,012	22,869,312	15,298,637	5,857,316	755.6	2,011,147	84,090	1,822,167	38.9	11,000	13,879	.3	90,865	171,650
Oklahoma	9,216,798	4,685,180	13,639,931	9,053,666	3,620,984	794.1	804,468	147,071	655,661	10.5		150,789	1.9	16,061	257,746
Oregon	6,106,896	3,097,814	9,503,408	5,970,497	2,659,625	462.0	492,704	64,950	332,215	6.4		38,544	.4	71,449	67,430
Pennsylvania	18,891,004	9,590,788	27,329,633	17,859,478	8,180,532	986.0	1,710,465	736,539	861,613	72.8	5,126	148,294	1.6	289,860	400,349
Rhode Island	1,998,708	1,014,572	2,982,260	1,998,708	850,540	88.0	151,901		150,183	1.1					13,848
South Carolina	5,459,165	2,770,954	7,240,911	5,213,787	1,827,521	586.1	558,305	34,110	502,236	29.2	125,330	219,597	11.0	85,938	221,600
South Dakota	6,011,479	3,047,643	8,456,446	5,731,526	2,167,147	1,471.0	665,341	28,392	636,949	61.0	81,536	133,788	23.6	170,025	109,760
Tennessee	8,492,619	4,302,991	12,447,422	8,298,288	3,247,894	473.5	1,165,557	191,703	877,453	19.1		10,343	.1	2,628	167,300
Texas	24,244,024	12,291,253	35,734,364	23,358,231	10,730,652	2,733.0	2,596,268	825,282	1,482,831	53.1		10,831	7.1	60,510	66,939
Utah	4,194,708	2,132,691	7,040,880	4,162,416	1,873,869	584.0	310,596		256,741	6.9	16,882		2.0	15,410	2,081
Vermont	1,867,573	948,007	3,032,652	1,863,531	842,013	137.6	114,167	3,922	95,623	2.4				120	10,371
Virginia	7,416,757	3,765,387	11,271,304	7,146,867	3,186,972	578.7	394,301	112,885	273,965	36.5	55,648	36,886	3.2	101,357	267,565
Washington	6,115,867	3,106,412	9,146,319	6,098,252	2,824,276	294.0	238,046		231,949	8.8	13,790	660		3,825	49,527
West Virginia	4,474,234	2,280,335	5,637,000	4,29[illegible].576	1,128,244	189.7	1,024,012	112,719	833,932	32.1	9,941	212,213	.9	54,999	105,945
Wisconsin	9,724,881	4,941,837	14,855,902	9,676,693	4,387,970	605.3	484,034	7,300	434,292	14.4		88,977		40,888	30,598
Wyoming	4,501,327	2,287,712	6,860,013	4,474,802	2,176,710	1,035.9	36,744	5,780	30,962	1.4		30,155		20,745	49,885
District of Columbia	1,918,469	973,842	2,645,015	1,909,584	735,296	20.0	222,699		187,199	2.3				8,885	51,348
Hawaii	1,871,062	949,778	2,308,775	1,774,496		44.0	1,012,501	82,369	914,171	11.5		14,000		14,196	21,607
TOTALS	394,000,000	200,000,000	582,815,830	378,162,956	154,084,743	33,677.5	50,197,186	11,192,202	34,500,381	1,338.6	1,240,286	4,734,359	251.8	3,404,556	6,680,517

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

A STUDY OF ROAD TARS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **R. H. LEWIS**, Associate Chemist, and **J. Y. WELBORN**, Junior Highway Engineer

THE Federal specifications used by the various agencies of the Federal Government include a number of standard specifications for tar products used in road construction. The road tar specifications that are in current use are summarized in table 1. This table lists the specification designation, the requirements for the physical and chemical properties of materials meeting particular grades, and the kinds of tars to be used in the preparation of the finished products.

While there may be considerable variation in test limits, the tests required by the Federal specifications are typical of those usually included in tar specifications throughout the United States. Some English and other European specifications limit the amount of ammonia, tar acids, naphthalene, and anthracene in their road tars, but American specifications generally do not.

The characteristics of the various grades of tars are dependent on the physical and chemical properties of the base tars used in their preparation. As shown in table 1, the materials that are generally specified for production of road tars are coal tars, either gas-house or coke-oven, and water-gas tars. The standard definitions of these products, A. S. T. M. designation D 8–33 are as follows:

Gas-house coal tar: Coal tar produced in gas-house retorts in the manufacture of illuminating gas from bituminous coal.

Coke-oven tar: Coal tar produced in byproduct coke ovens in the manufacture of coke from bituminous coal.

Water-gas tars: Tars produced by cracking oil vapors at high temperatures in the manufacture of carbureted water gas.

The properties of these tars can be greatly altered not only by the character of the oil or coal used but also by the methods and temperatures involved in the various processes used in their production. For instance, for many years carbureted water gas was manufactured using gas oil, a fraction of petroleum distillate coming off immediately after the kerosene fraction. In recent years fuel oil, which is either a heavier distillate or a mixture of distillate with a base petroleum, has also been utilized for carburetion. The tars resulting from the use of the two types of oil have widely different properties.

J. Edwards has stated [1] that while the usual laboratory tests are of value, future control must not be limited to laboratory tests only. He intimated that the amount and kind of base tar and the kind and quantity of blending oils should also be specified, since these are vital factors that determine the suitability of the tar for a particular use. Some States have already adopted such specifications. The following 1934 specification of a State highway department for a coal-tar cutback is of this type and not only sets specification limits for the finished product but also specifies the test characteristics of the base and flux used in producing the material.

STATE SPECIFICATION FOR COAL-TAR CUTBACK DISCUSSED

This specification covers coal-tar cutback for treatment of earth roads as follows: This material shall contain not less than 40 nor more than 90 percent by volume of refined coal-tar base, fluxed with a tar material (liquid at 60° F.), which shall make a homogeneous mixture. The flux shall be a water-gas tar or either distillates of water-gas tar or coal tar or a combination of water-gas tar and the above distillates. The flux, base, and mixture shall conform to the requirements shown in table 2, in which the specific viscosity of the mixture will be subject to variation within the limits designated, as may be directed.

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[1] Prepared Tars and Their Application to Road Construction. Roads and Road Construction, vol. XIII, no. 147. March 1935.

TABLE 1.—*Summary of Federal specifications for tar products used in road construction*

Federal specification designation	Consistency				Specific gravity at 25°/25° C.	Bitumen (soluble in CS_2)	Total distillate (by weight)—				Softening point of distillation residue	Water	Produced from
	Engler specific viscosity		Float test				To 170° C.	To 235° C.	To 270° C.	To 300° C.			
	At 40° C.	At 50° C.	At 32° C.	At 50° C.									
			Seconds	*Seconds*		*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*° C.*	*Percent*	
TC-1-25	8–13	--------	--------	--------	1.090+	90+	7−	--------	32−	42−	60−	2−	Gas-house, coke-oven, water-gas and/or similar tars.[1]
TC-2-25	13–18	--------	--------	--------	1.090+	90+	5−	--------	30−	40−	60−	2−	
TC-3-25	18–25	--------	--------	--------	1.100+	90+	5−	--------	30−	40−	60−	2−	
TC-4-25	25–35	--------	--------	--------	1.10–1.18	90+	3−	--------	30−	40−	60−	2−	
TM-1	--------	16–26	--------	--------	1.10–1.22	87+	5−	--------	25−	[2] 35−	35–60	2−	Gas-house, coke-oven, and/or water-gas tars.[1]
TM-2	--------	26–36	--------	--------	1.10–1.22	87+	5−	--------	25−	[2] 35−	35–60	2−	
TR-1-25	35–60	--------	--------	--------	1.09–1.19	80+	2–8	8–20	16–28	36−	65−	2−	Refined gas-house, coke-oven and/or water-gas tars fluxed with suitable distillates.[1]
TR-2-25	60–80	--------	--------	--------	1–10–1.20	80+	2–8	8–20	16–28	36−	65−	2−	
TH-1 [3]	--------	--------	60–150	--------	1.140+	85+	1−	--------	15−	25−	65−	0	Gas-house, coke-oven, water-gas, and/or similar tars.[4]
TP-1-25	--------	--------	--------	100–160	1.15–1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-2-25	--------	--------	--------	100–160	1.20–1.26	80–95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar [4]
TP-3-25	--------	--------	--------	130–190	1.15–1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-4-25	--------	--------	--------	130–190	1.20–1.26	80–95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar.[4]
TP-5-25	--------	--------	--------	160–220	1.15–1.20	95+	1−	--------	10−	20−	65−	0	Refined water-gas tar.[4]
TP-6-25	--------	--------	--------	160–220	1.20–1.26	80–95	1−	--------	10−	20−	65−	0	Gas-house and/or coke-oven tar [4]

[1] The material shall be homogeneous.
[2] Specific gravity of total distillate 38°/38° C. minimum (water free), 0.96.
[3] The Federal specifications designate this material as refined hot-application tar. For convenience, the designation TH-1 is used in this report.
[4] The material shall be homogeneous and free from water.

TABLE 2.—*Requirements for flux, base, and mixture of a coal-tar cutback*

	Flux		Base		Mixture	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Water, percent by weight						2.0
Specific gravity at 25°/25° C	1.00	1.12	1.14	1.22	1.11	1.16
Specific viscosity, Engler:						
50 cubic centimeters at 50° C			6.0	30.0		
50 cubic centimeters at 40° C	1.1	3.6			5.0	8.0
Soluble in carbon disulphide, percent by weight	96		88	97	89	98
Distillation (A. S. T. M.):						
0-170° C., per cent by weight		7		4.5		7
0-300° C., per cent by weight	25	87		35		45
Specific gravity at 38°/38° C. of total distillate (water free) to 300° C			1.00		0.96	
Softening point of distillation residue, ° C. (ring and ball method)				65	35	60

Where the consumer has adqeuate facilities for plant inspection, a specification of this type may be advantageous. However, with the usual laboratory control, test requirements on the finished products will usually prove satisfactory. As shown in table 1, the Federal specifications give the tar refiners considerable leeway in the manufacture of the various grades of road tar from their available sources of crude tar. With the exception of the TP grades 1, 3, and 5, that require the materials to be refined water-gas tar, and the TP grades 2, 4, and 6, that require the materials to be refined from suitable gas-house and/or coke-oven tars, all other grades allow the producer to use a tar from a single source or to blend such materials as any of the above with or without suitable distillates as may be necessary to meet the specification.

The Federal specifications, as well as specifications of the special type already described, control the quality and grade of tar products suitable for various types of road construction by consistency tests, such as the viscosity and float tests, by determination of free carbon,[2] and by an accelerated laboratory evaporation test. The evaporation test in general use for all tar products is the distillation test, which not only gives the amount of total volatile matter present in the tar but also indicates the probable rate at which these volatile constituents may be lost under service conditions. A softening point determination on the residue from distillation has been considered as a measure of consistency of the material that would be present as active binder when the volatile matter has evaporated from the road surface.

In order to determine how present-day tars conform to the Federal specifications, 35 tar products were obtained from 5 of the leading tar refiners. The laboratory study of these materials is the subject of this report.

TYPICAL GRADES OF ROAD TAR FROM MAJOR PRODUCERS STUDIED

In table 3 the samples of these road tars are grouped according to their conformity to Federal specification grades, and the composition of the materials as reported by the producers is shown. The intended use of the Federal specification grades, as well as the use recommended by the producers, are also given. Samples 22, 23, and 31, submitted by producer C and designated as "special", did not meet any particular specification.

TABLE 3.—*Comparison of road tars with standard Federal specifications*

Bureau laboratory no.	Identification	Standard Federal specification		Information furnished by producer		
		Grade	Intended use	Produced by	Produced from—	Intended use
37996	7	TC-1-25	Prime	B	Water-gas tar	Prime.
39003	14			C	Bunker C tar+water-gas tar	Do.
39009	20			C	Coal tar+water-gas tar	Do.
39016	24			D	Coal tar+water-gas tar and/or distillate.	Do.
37990	1	TC-2-25	Surface treatment	A	Coal tar+water-gas tar [1]	Do.
39004	15			C	Bunker C tar+water-gas tar	Light surface treatment.
39010	21			C	Coal tar+water-gas tar	Do.
39028	33			E	do.[2]	Light surface treatment and prime.
39005	16	TC-3-25	do	C	Bunker C tar+water-gas tar	Heavy surface treatment and honing.
39017	25			D	Coal tar+water-gas tar and/or distillate.	Cold surface treatment.
37992	3	TC-4-25	do	A	Coal tar+water-gas tar [1]	Do.
39006	17			C	Bunker C tar+water-gas tar	Mulch honing.
37997	8	TM-1	Mixed-in-place surfaces, open-graded aggregate.	B	Water-gas tar	Cold surface treatment. Reclamation work.
38000	11			B	do	Retread or mixed-in-place.
39007	18			C	Bunker C tar+water-gas tar	Mulch honing.
39030	35			E	Coal tar+water-gas tar [2]	Retread or mixed-in-place.
37994	5	TM-2	do	A	do.[1]	Retread construction.
39008	19			C	Bunker C tar+water-gas tar	Mixed-in-place with broken stone.
39018	26			D	Coal tar+water-gas tar and/or distillate.	Mixed-in-place and drag surface treatment.
37998	9	TR-1-25	Repair work (used cold)	B	Water-gas tar	Patching (used cold).
37995	6	TR-2-25	Repair work (usually warmed)	A	Coal tar+distillate [1]	Repair work.
37999	10			B	Water-gas tar	Repair work (used warm).
39019	27			D	Coal tar+distillate	Repair work (used cold).
37991	2	TH-1	Hot surface treatment	A	Coal tar [1]	Hot surface treatment.
39001	12			B	Water-gas tar	Hot surface treatment and seal coat.
39027	32			E	Coal tar+water-gas tar [2]	Hot surface treatment; wearing coat or seal.
39020	28			D	Coal tar	Hot surface treatment; second application for mixed-in-place.
39002	13	TP-1-25	Bituminous macadam	B	Water-gas tar	Penetration macadam.
39021	29	TP-2-25	do	D	Coal tar	Hot repair and crack filler.
37993	4	TP-4-25	do	A	do.[1]	Penetration macadam.
39022	30	TP-6-25	do	D	do	Do.
39029	34			E	Coal tar+water-gas tar [2]	Do.
39011	22	Special		C	Coal tar	
39012	23	do		C	Thin water-gas tar	Flux for samples 14, 15, 16, 17, 18, and 19.
39026	31	do		C	Bunker C tar	Base for samples 14, 15, 16, 17, 18, and 19.

[1] No information furnished. Classification based on test results.

[2] Classification based partly on information furnished by producer and partly on test results.

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[2] Free carbon in tars is defined by the American Society for Testing Materials designation D 8-33 as organic matter that is insoluble in carbon disulphide. The term will be so used in this report.

One or more of the other samples represented each of the specification grades shown in table 1, except grades TP–3 and TP–5. These grades are for refined water-gas tars that have the same range in consistency as the coal tar grades TP–4 and TP–6, respectively.

The laboratory study of these road tars included tests to determine their conformity with the particular Federal specifications, and other tests which, although not usually made on road tars, might develop information of value relative to their physical and chemical characteristics. In order to determine how these materials lose their volatile matter under accelerated weathering conditions and to determine the character of the resulting residues, all of the tars were exposed in thin films to the action of air, light, and solar heat. The residues from exposure and the distillation residues were subjected to the same laboratory tests so that the physical and chemical characteristics of the residues obtained by both methods might be compared.

In order to determine the binding values of the original materials and of their distillation residues, Hubbard-Field stability cylinders were made with these materials combined with a standard sand and the stability of these cylinders was determined. Cylinders containing the original tars and exposed under the same conditions as the thin films were tested for stability to determine the development of binding value under accelerated weathering.

The laboratory tests made on the 35 tar products to show their conformity to the various Federal specification grades were as follows:

Specific gravity at 25°/25° C.
Specific viscosity, Engler, at 40° C. and 50° C.
Float test at 32° C. and 50° C.
Solubility in carbon disulphide.
Distillation test, A. S. T. M. D 20–30.
Softening point of distillation residue.

The laboratory tests made to obtain data of special interest were:

Specific viscosity, Engler, at 60° C.
Saybolt-Furol viscosity at 25°, 40°, 50°, and 60° C.
Specific gravity at 38°/38° C. of total distillate.
A. S. T. M. method D 402–34 T of pouring distillation residue.
Softening point of residue obtained under above method.
Ductility at 10°, 15°, 20°, and 25° C. on residues from A. S. T. M. D 20–30 distillation.

The A. S. T. M. and A. A. S. H. O. designations of methods of making these tests are given in table 4.

TABLE 4.—*Tests methods used in studying road tars*

Test	Method of test	
	A. S. T. M. designation	A. A. S. H. O. designation
Specific gravity	D 70–27	T–43.
Specific viscosity, Engler		T–54.
Saybolt-Furol viscosity	D 88–33	T–72.
Float test	D 139–27	T–50.
Penetration	D 5–25	T–49.
Softening point, ring and ball	D 36–26	T–53.
Ductility	D 113–26 T	
Solubility in CS $_2$	D 4–27	T–44.
Water	D 95–30	T–55.
Distillation	D 20–30	T–52.
Do	D 402–34 T.	T–78.

TARS STUDIED WERE IN GENERAL CONFORMANCE WITH FEDERAL SPECIFICATIONS

The results of laboratory tests made to determine conformity with Federal specifications are given in table 5 and show that only four of the road tars failed to meet all of the requirements of the specifications for the appropriate grades of material. The softening point of the distillation residue of sample 17 was 0.4° C. over the maximum limit for TC–4 material. The amount of distillate of sample 27 up to 170° C. was 0.51 percent under the minimum limit for TR–2 material. The float of sample 28 was 215 seconds, or 65 seconds greater than the specification requirement for TH–1 material. Sample 13 failed to meet the specification for TP–1 material which requires the solubility in carbon disulphide to be greater than 95 percent. The three specifications for TP materials produced from water-gas tars require high solubility in carbon disulphide.

Samples 22, 23, and 31 did not meet any particular specification. The tests on sample 22, a heavy, dehydrated coal tar, indicated that it had too high a free carbon content to be satisfactorily processed, without fluxing, to meet any of the Federal specifications. Sample 23 was a very thin, water-gas tar, too fluid for direct use in road construction. Sample 31, while meeting the specification for TH–1 material except that its residue from distillation had too high a softening point, was submitted with sample 23 as the base and flux, respectively, which producer C used in the road tars represented by samples 14 to 19 inclusive. Using the specific gravities of samples 23 and 31 and assuming no change in volume when mixing these two products, samples 14, 15, 16, 17, 18, and 19 contained approximately, by weight, 30, 35, 40, 45, 50, and 55 percent, respectively, of sample 31 as the base in the blended tars. Although the percentage composition of the other blended tars could not be definitely established, the more fluid materials having the lowest densities were perhaps chiefly water-gas tars. The blends of water-gas tars, bunker C water-gas tar, and the blends of coal tar and water-gas tars had high densities.

The percentage of free carbon has been limited to a great extent by specifications, there being still a considerable difference of opinion as to whether a high or a low free-carbon tar is more suitable for a particular purpose. For the heavier grades of tar, such as refined tars of the TP grades, the Federal specifications provide for a coal tar of high free-carbon content and a water-gas tar of low free-carbon content. For the other grades, the minimum amount of free carbon permissible is not limited. A study of the solubility of these tars submitted by the various producers indicates that in general the percentage of insoluble material is well under the maximum allowable by the Federal specifications.

Comparing the materials meeting the various specification grades as a group, it will be seen that the TC materials were most soluble in carbon disulphide and the TR and TP materials the least soluble. The TM materials had a solubility close to the TC tars, and the solubility of the TH products was slightly more than that of the TR and TP samples. The average solubilities for the various grades were as follows: TC, 93.56 percent; TM, 92.21 percent; TR, 88.01 percent; TH, 89.58 percent; and TP, excluding sample 13, 88.02 percent. All of the materials, except sample 13, had solubilities in carbon disulphide well within the specification limits for their particular grades.

MOST FLUID TARS HAD GREATEST LOSS ON DISTILLATION

The distillation test has been generally used in the testing of tars to determine the amount of volatile matter and to determine the probable rate of volatilization of the constituents having low boiling points.

TABLE 5.—*Results of laboratory tests on road tars, showing conformity with Federal specifications*

Type of material	Identification	Specific gravity at 25°/25° C	Engler specific viscosity—		Float test—		Carbon disulphide solubility[1]			Water	Distillation (by weight)[1]					Specific gravity of distillate at 38°/38° C	Softening point of residue
											Total distillate				Residue		
			At 40° C	At 50° C	At 32° C	At 50° C	Bitumen	Free carbon	Inorganic matter insoluble		To 170° C	To 235° C	To 270° C	To 300° C			
					Seconds	*Seconds*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*		*°C*
TC-1	(2)	1.090+	8-13				90+			2–	7–		32–	42–			60–
	7	1.108	9.2				91.77	8.15	0.08	1.3	2.00	14.67	25.79	35.15	64.10	0.971	45.0
	14	1.115	10.7				93.77	6.10	.13	1.4	1.16	12.67	26.56	37.42	61.96	.975	54.8
	20	1.138	9.5				95.22	4.71	.07	.6	.89	11.68	22.27	31.76	67.94	1.002	47.4
	21	1.150	11.8				93.27	6.61	.12	0	.29	12.70	25.22	34.02	65.65	1.013	45.2
TC-2	(2)	1.090+	13-18				90+			2–	5–		30–	40–			60–
	1	1.132	15.9				93.78	6.06	.16	.8	.42	7.46	21.25	32.86	66.81	.992	44.6
	15	1.123	15.5				93.41	6.45	.14	1.3	1.04	11.36	25.50	35.78	63.66	.978	55.6
	21	1.151	17.3				94.51	5.42	.07	.7	1.00	10.55	20.88	28.91	70.75	1.016	50.8
	33	1.138	16.2				96.13	3.76	.11	.3	.17	6.85	18.63	29.54	70.08	1.009	37.0
TC-3	(2)	1.100+	18-25				90+			2–	5–		30–	40–			60–
	16	1.127	21.2				93.05	6.75	.20	1.4	.99	9.38	23.54	34.50	64.50	.980	57.1
	25	1.162	20.7				92.56	7.17	.27	0	.25	10.98	22.94	31.34	68.11	1.017	46.6
TC-4	(2)	1.10-1.18	25-35				90+			2–	3–		30–	40–			60–
	3	1.150	34.9				92.43	7.50	.07	.7	.84	7.11	19.59	28.25	70.90	.999	45.0
	17	1.135	32.5				92.88	6.91	.21	1.0	.83	8.92	22.68	34.21	65.22	.982	60.4
TM-1	(2)	1.10-1.22		16-26			87+			2–	5–		25–	35–		.96+	35-60
	8	1.129		21.1			91.14	8.73	.13	0	.77	6.99	17.62	25.98	73.95	1.004	41.0
	11	1.135		24.8			91.33	8.57	.10	0	0	3.76	16.45	27.13	72.43	.991	42.0
	18	1.140		22.6			92.42	7.33	.25	1.1	.68	7.34	21.03	32.15	66.58	.984	59.4
	35	1.159		22.2			95.19	4.70	.11	.5	.39	5.30	15.92	25.39	74.69	1.019	39.6
TM-2	(2)	1.10-1.22		26-36			87+			2–	5–		25–	35–		.96+	35-60
	5	1.166		27.4			91.69	8.23	.08	.5	.61	5.08	16.29	25.08	74.27	1.007	46.1
	19	1.145		31.6			92.35	7.44	.21	1.3	.74	7.73	20.20	31.09	68.11	.986	60.0
	26	1.189		32.0			91.32	8.44	.24	0	.19	4.02	13.96	23.04	76.60	1.030	43.2
TR-1	(2)	1.09-1.19	35-60				80+			2–	2-8	8-20	16-28	36–			65–
	9	1.136	44.5				88.05	11.67	.28	0	5.09	15.69	21.56	27.30	72.25	.963	60.0
TR-2	(2)	1.10-1.20	60-80				80+			2–	2-8	8-20	16-28	36–			65–
	6	1.175	60.7				83.79	16.21	.00	.6	2.34	10.83	17.38	25.19	74.10	.987	53.1
	10	1.130	73.1				91.59	9.16	.25	0	2.31	12.29	18.76	24.90	74.48	.948	55.8
	27	1.180	63.1				88.61	11.34	.05	0	1.49	12.95	18.46	25.16	74.55	.988	55.4
TH-1	(2)	1.140+			60-150		85+			0	1–		15–	25–			65–
	2	1.214			129		85.21	14.79	.00	0	0	4.16	11.65	19.23	80.20	1.034	51.7
	12	1.166			102		89.60	10.22	.18	0	0	1.36	5.84	15.16	84.46	.999	41.6
	32	1.187			80		93.19	6.81	.00	0	0	.55	3.42	10.81	88.88	1.044	33.1
	28	1.222			215		90.31	9.65	.04	0	0	1.33	5.69	13.89	85.63	1.053	47.0
TP-1	(2)	1.15-1.20				100-160	95+			0	1–		10–	20–			65–
	13	1.174				107	89.09	10.73	.18	0	0	1.03	4.37	11.60	88.21	1.002	49.0
TP-2	(2)	1.20-1.26				100-160	80-95			0	1–		10–	20–			65–
	29	1.223				126	88.70	11.22	.08	0	0	1.13	4.47	11.40	88.28	1.055	49.6
TP-4	(2)	1.20-1.26				130-190	80-95			0	1–		10–	20–			65–
	4	1.237				167	83.56	16.37	.07	0	0	.95	4.08	12.21	86.80	1.043	56.1
TP-6	(2)	1.20-1.26				160-220	80-95			0	1–		10–	20–			65–
	30	1.219				194	87.76	12.23	.01	0	0	.25	2.02	8.41	91.28	1.058	51.8
	34	1.206				165	92.06	7.91	.03	0	0	.20	1.42	5.72	94.10	1.019	44.1
Special	22	1.233			45	30	78.84	21.09	.07	.20	.43	5.28	13.22	19.71	80.38	1.018	58.5
	23	1.082	2.0				94.74	5.03	.23	.8	1.29	18.46	35.17	47.37	52.15	.965	39.1
	31	1.196			117		87.15	12.74	.11	0	.71	5.25	9.97	18.11	81.10	.998	73.3

[1] Water-free basis.

[2] Federal specification.

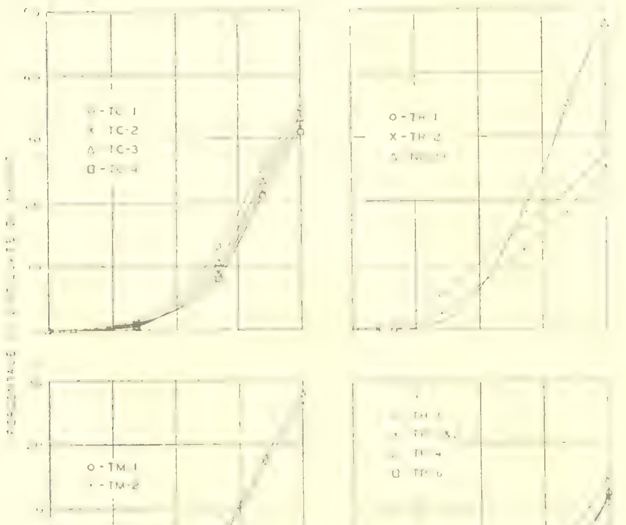

FIGURE 1.—RELATIONS BETWEEN AMOUNT OF DISTILLATE BY WEIGHT AND DISTILLING TEMPERATURE FOR VARIOUS GRADES OF ROAD TARS.

The average distillation curves for the various grades of road tars are shown in figure 1. For the different materials of the same grade the amount of distillate at the temperatures used for fractionating was fairly close to the average value shown by the curves, except for the TH materials.

It will be seen from figure 1 that there is a relation between the distillation loss at 300° C. and the consistency of the original material—the TC–1 grade, which was the most fluid, had the greatest loss and the TP–6 grade, which was the most viscous, had the smallest loss. Of the tars for cold application[3] only the TR–1 and TR–2 grades had a uniform rate of loss from 170° C. to 300° C. and both types of material, used primarily for patch work, had distilled off a greater percentage of their total distillate at 170° C. than did the other cold-application materials. The TC grades had given off a relatively small amount of their total distillate at 170° C. The curves for TM–1 and TM–2 products are similar to the TC curves.

All of the tars for hot application showed no distillate to 170° C. and the rate of loss increased from 235° C.

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[3] In the following discussion the TC, TM, and TR grades are referred to as tars for cold application or cold tars, and the TH and TP grades as tars for hot application or hot tars.

to 300° C. for all grades. The curves, as a whole, show that the cold-application tars contained a relatively high percentage of constituents having low boiling points, and that in service their ultimate consistency is reached almost entirely through the loss of their volatile matter. For the hot-application tars the high boiling point of the contained distillates and the smaller percentage of total distillate to 300° C., together with the more viscous consistency of the various grades, indicate that their binding properties while increasing with service are, initially, not dependent upon the loss of the more volatile constituents.

Although the Federal specifications for road tars do not contain requirements for the specific gravity of the total distillate except for the TM grades, this requirement appears in many State specifications for tar products. The determination of specific gravity at 38°/38° C. was made on the recovered distillate of all the tars tested.

The data obtained are tabulated in table 6 and may be of some assistance in identifying the types of materials used in the manufacture of road tars. The materials classed as water-gas tars, which include the mixtures of water-gas tar with bunker C tar, had distillates ranging in specific gravity from 0.948 to 1.004 with an average of 0.982. The mixtures of coal tar and water-gas tar had distillates ranging in specific gravity from 0.992 to 1.044 with an average of 1.014. The distillates from coal tars and coal tars thinned with istillate ranged in specific gravity from 0.987 to 1.058 with an average of 1.030.

There is undoubtedly considerable overlapping in the range in values of specific gravity of the distillates of the tars in each classification. However, as shown in table 6, where two or more types of materials met a single specification grade, the distillates of the water-gas tars had the lowest specific gravity, the distillates of the coal tar and water-gas tars, with the exception of the TH-1 grade, were next, and the coal-tar distillates had the highest. While a specification limit for the specific gravity of the total distillate is only required in the TM grades of the Federal specifications, the test is considered of value by the producers and by others. When properly correlated with other test data it can be used to identify the type of tar. A specific gravity test of the distillate can also be used to detect the presence of petroleum admixtures.

TABLE 6.—*Specific gravities of total distillates from A. S. T. M. D 20-30 distillation test*

Grade	Type of material					
	Water-gas tar		Coal tar and water gas tar		Coal tar	
	Identification	Specific gravity at 38°/38° C.	Identification	Specific gravity at 38°/38° C.	Identification	Specific gravity at 38°/38° C.
TC-1	7	0.971	20	1.002		
	14	.975	24	1.013		
TC-2	15	.978	1	.992		
			21	1.016		
			33	1.009		
TC-3	16	.980	25	1.017		
TC-4	17	.982	3	.999		
TM-1	8	1.004	35	1.019		
	11	.991				
	18	.984				
TM-2	19	.986	5	1.007		
			26	1.030		
TR-1	9	.963				
TR-2	10	.948			6	0.987
					27	.988
TH-1	12	.999	32	1.044	2	1.034
					28	1.053
TP-1	13	1.002				
TP-2					29	1.055
TP-4					4	[illegible]
TP-6			34	1.019	30	1.058
Special	23	.965			22	1.018
Do	31	.998				
Average		.982		1.014		[illegible]

The consistency of the distillation residue is usually determined by a softening-point test. The softening point of the distillation residues ranged from 37.0 to 60.4, with an average of 49.9 for the cold-application materials, and from 33.1 to 56.1, with an average of 47.1 for the hot-application materials. It will be seen from table 5 that, in each grade, the road tars from producer E had the softest residues.

SAYBOLT-FUROL VISCOSIMETER SATISFACTORY FOR DETERMINING CONSISTENCIES OF FLUID ROAD TARS

One of the most important characteristics of road tars is the consistency or degree of fluidity. Road tars are used as penetrative treatments, as surface treatments and seals, and as binders in road-mix or premix construction. The ease of application, the workability of the mixes, and the development of stability in the road surface are to a great extent dependent upon the initial consistency of the tar used.

Many different tests to measure the consistency of road tars have been developed. E. O. Rhodes,[4] working with normal byproduct coke-oven tars, showed the interrelationship of test values obtained with different instruments used to measure consistency. Although he did not stress either the accuracy of the various tests or the speed or ease of making them, he reached the following conclusion: "The use of the Engler specific viscosities at 40° C. and at 50° C., and the float tests at 32° C. and 50° C., discarding all other consistency measurements, would contribute greatly to the simplification and improvement of road-tar specifications."

The materials meeting the Federal specifications and the road-tar specifications of most States generally have been controlled by a determination of the Engler specific viscosity or the float test as proposed. Although the Saybolt-Furol viscosimeter has been adopted by the State and Federal testing laboratories for determining the consistency of liquid asphaltic road materials, the Engler specific viscosity determination has been generally retained in road-tar specifications. Since the Saybolt-Furol instrument has many advantages over the Engler instrument all of the tars used in this investigation, with the exception of the tars for heavy construction, were tested by both methods. The more viscous products were subjected to the float test. All of the consistency determinations on the original materials are given in table 7.

In order to determine the relation between test values as obtained with the two viscosimeters, the data in table 7 have been plotted in figures 2 and 3.

In figure 2 the Saybolt-Furol viscosity in seconds at 40° C., 50° C., and 60° C. is compared with the Engler specific viscosity at the same temperature for each particular tar. The points fall quite close to a straight line having a slope of 1 to 4, that is, the Saybolt-Furol viscosity in seconds at the temperatures used is approximately 4 times the Engler specific viscosity at the same temperature. The viscosity values obtained on

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[4] A Discussion of Road Tar Consistency Relationships, Engineering News-Record, vol. 111, no. 16, October 19, 1933.

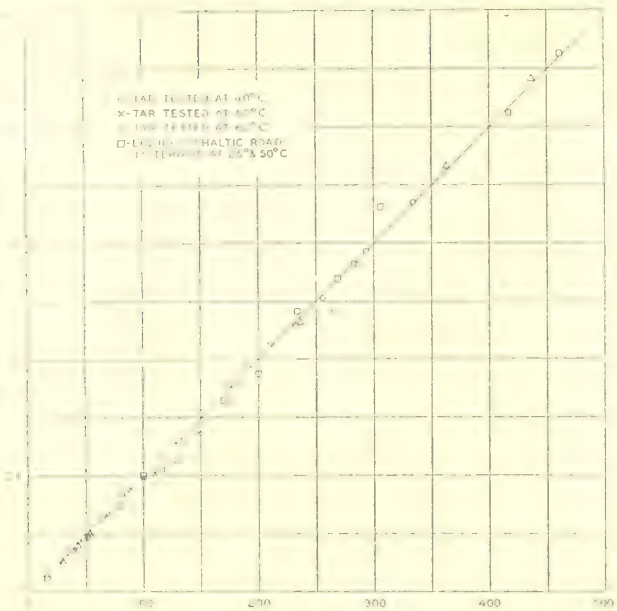

FIGURE 2.—COMPARISON OF SAYBOLT-FUROL AND ENGLER SPECIFIC VISCOSITIES OF ROAD TARS.

TABLE 7.—*Consistencies of the original materials*

Type of material	Identification	Engler specific viscosity— At 40° C.	Engler specific viscosity— At 50° C.	Engler specific viscosity— At 60° C.	Saybolt-furol viscosity— At 25° C.	Saybolt-furol viscosity— At 40° C.	Saybolt-furol viscosity— At 50° C.	Saybolt-furol viscosity— At 60° C.	Float test— At 32° C.	Float test— At 50° C.
					Seconds	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*
TC-1	7	9.2			88	37				
	14	10.7	6.3		118	44				
	20	9.5			142	41				
	24	11.8	6.3		167	51	28			
TC-2	1	15.9	8.0		238	65	34			
	15	15.5	8.5		185	64				
	21	17.3	8.4		342	73	36			
	33	16.2	8.0		263	67	32			
TC-3	16	21.2	11.2	6.6	277	86	47	30		
	25	20.7	9.5		322	82	40			
TC-4	3	34.9	15.4	8.0	652	142	63	35		
	17	32.5	16.5	9.5	490	136	68	40		
TM-1	8	40.1	21.1	11.6	647	176	84	49		
	11	53.5	24.8	13.4		212	100	53		
	18	48.5	22.6	12.5		192	93	53		
	35	57.4	22.2	10.0		233	90	43		
TM-2	5	70.4	27.4	12.9		287	116	54		
	19	70.6	31.6	16.7		283	129	68		
	26	83.7	32.0	14.5		334	129	62		
TR-1	9	44.5	22.0	13.6		181	105	55		
TR-2	6	60.7	26.9	12.9		267	114	56		
	10	73.1	32.7	18.5		294	149	78		
	27	63.1	25.5	13.1		256	111	56		
TH-1	2			91.4				363	129	58
	12			110.5				436	102	51
	32			57.6				237	80	43
	28								215	78
TP-1	13									107
TP-2	29								633	126
TP-4	4								1,977	167
TP-6	30									194
	34									165
Special	22			44.7				175	45	30
	23	2.0			15	12				
	31			142.7				520	117	51

some liquid asphaltic materials fall along the same line. This indicates that the relation between the two viscosity tests made on both types of bituminous materials at the same test temperature is quite close.

Frequently it is desired to convert the viscosity at one temperature to the viscosity at another temperature. Many temperature-viscosity conversion tables and charts for both asphaltic and tar products have been published but, as stated by E. O. Rhodes,[4] they are accurate only when materials from the same source and method of manufacture are compared.

The relations existing between the Saybolt-Furol viscosities at different temperatures are shown in figure 3. Because of the varied sources of material and methods of blending no satisfactory average curve could be drawn for all materials, although a definite trend is indicated. This makes it possible to distinguish to a certain degree the source of the various tars. Those materials that are known to be water-gas tars are in

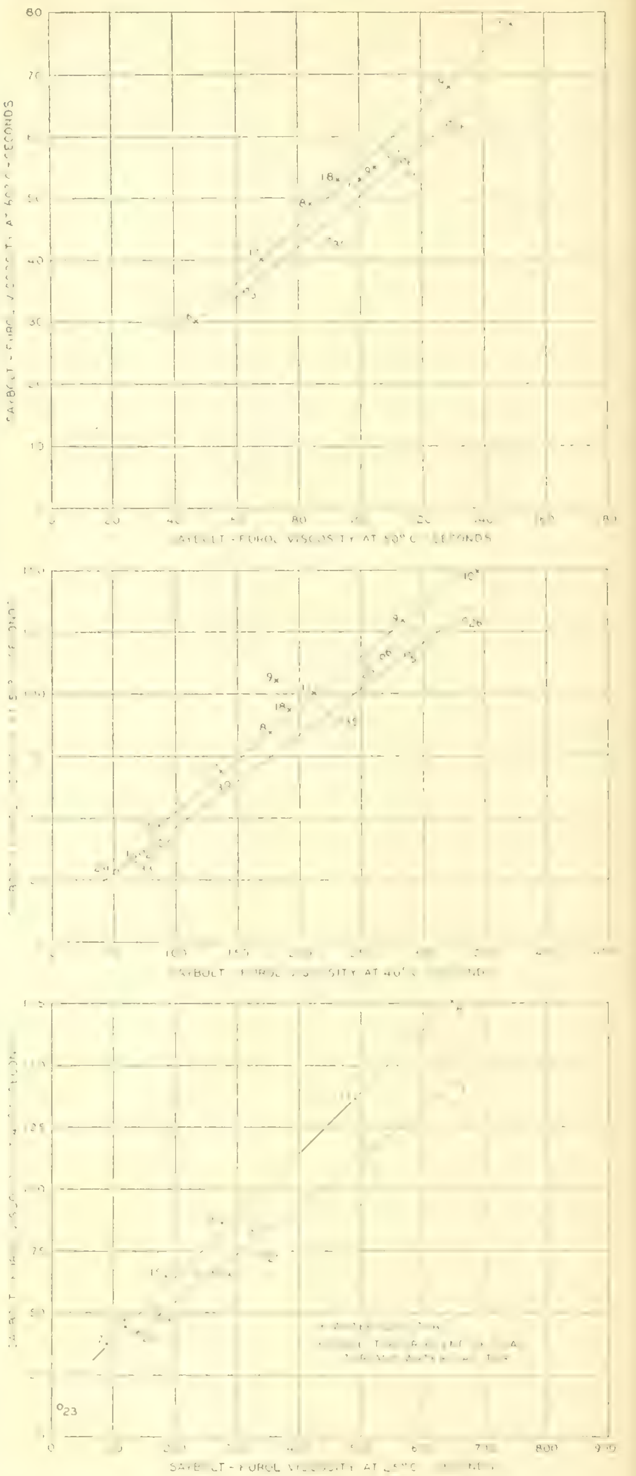

FIGURE 3.—RELATIONS BETWEEN SAYBOLT-FUROL VISCOSITIES OF VARIOUS ROAD TARS AT VARIOUS TEMPERATURES.

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[4] [illegible] of Road Tar Consistency Relationships. Engineering News-[illegible] 111, no. 16, October 19, 1933.

nearly every case above the location of an average curve. Below the average curves are those materials known to be, or interpreted from results of tests to be, coal tars or blends of coal tars. In other words, based on viscosity tests, water-gas tars are somewhat less susceptible to temperature change than are the coal tars or coal-tar blends.

TEST PROCEDURE FOR TARS SUBSTANTIALLY DIFFERENT FROM THAT FOR ASPHALTIC MATERIALS

The float test at 32° C. has been generally adopted as a measure of consistency for the tars for hot surface treatments although the data in table 7 show that the use of Saybolt-Furol viscosity at 60° C. might also be satisfactory. However, for the heavy construction tars of the TP grades, the standard Saybolt-Furol test would not be suitable. The specifications of the American Society for Testing Materials for materials of this type require a softening point determination as a measure of consistency with the option of using the float test at 50° C., while the Federal specifications control consistency by means of the float test at 50° C. only. As indicated by table 7, the use of 50° C. as the temperature for the float test is to be preferred to 32° C. because of the greatly reduced time involved in making the test.

On the basis of the data developed by this investigation, it is believed that the float test at 32° C. and 50° C. is a satisfactory test for the consistency of the hot-application tars. Since the Saybolt-Furol viscosimeters with thermostatic control can be operated to give close checks on duplicate tests, require less material for test, and greatly shorten the time of testing, the adoption of Saybolt-Furol viscosity for cold application road tars, as has been done for liquid asphaltic road materials, would be a pronounced advance toward the general simplification and standardization of tests for this type of bituminous material.

In connection with this discussion of the measurement of consistency, mention should be made of a new viscosimeter.[5] This instrument is designed to measure the viscosity of all grades of bituminous material at a single temperature and the results are expressed in terms of the absolute viscosity, the poise. Much preliminary work must be done before general adoption of this new test can be expected, but its possibilities are such that it merits serious consideration. It presents a possible means of overcoming the present disadvantages of using several methods for measuring consistency and several temperatures for each method.

While there do not appear to be any practical reasons why all bituminous materials should not be tested in the same manner, for years the test procedure for tars has been substantially different from that for asphaltic materials. For tars, the amount of volatile matter has been determined by the distillation test and the materials have not usually been submitted to the volatilization test (loss on heating at 163° C.) which has been extensively used for liquid asphaltic materials. The volatilization test has been discarded rather generally, especially for the more rapid-hardening, liquid asphaltic products, and a distillation test has been substituted to determine the amount and rate of loss of volatile matter.

The method of making the distillation test for liquid asphaltic materials is described in A. S. T. M. Tentative Method of Test for Separation of Liquid Asphaltic Products, designation D 402-34 T, while the distillation test for tars is A. S. T. M. Standard Method of Test for Distillation of Bituminous Materials Suitable for Road Treatment, designation D 20-30. There are some essential differences that might lead to the belief that the results obtained by the two methods would be radically different.

Both methods use the same flask and thermometer. Method D 20-30 requires an air condenser; method D 402-34 T requires a water condenser. In the tar distillation the top of the bulb of the thermometer is at the bottom of the tubulature and the vapor temperature controls the distillation cuts and end point. In the liquid asphalt distillation the bottom of the bulb of the thermometer is ¼ inch above the bottom of the flask and the distillation fractions and end point are controlled by the temperature of residue or the liquid temperature. In the distillation of tars a 100-gram sample is used, while in the distillation of liquid asphaltic materials a 200-cubic centimeter sample is used.

The percentage of distillate is reported by weight in the tar distillation and by volume in the distillation of the liquid asphaltic material. The end point for the distillation of tar products is 300° C. (572° F.) vapor temperature. The end point of the distillation of asphaltic materials is 360° C. (680° F.) liquid temperature. The tar residue is cooled in the flask below 125° C. (257° F.) before pouring for further tests. The asphaltic residue is poured as quickly as possible after the end point of the distillation is reached.

In order to make some comparison of the results obtained by the two methods, 100-gram samples of one tar of each grade were distilled with two thermometers in the flask, so that the vapor temperature at the tubulature and the liquid temperature ¼ inch above the bottom of the flask could be determined. The relations between the vapor and liquid temperature are shown in figure 4.

METHOD OF POURING DISTILLATION RESIDUES AFFECTS THEIR PROPERTIES

The curves indicate quite clearly that for these tars, with one exception, a vapor temperature of 300° C. (572° F.) corresponds to a liquid temperature somewhat below 360° C. (680° F.). The one exception is the tar of the TC grade for which the vapor temperature of 300° C. corresponds to a liquid temperature slightly in excess of 360° C. The rather close agreement between a vapor temperature of 300° C. and a liquid temperature of 360° C. indicates that for these tar products there can be no great difference either in the amount of distillate or character of the residue, due solely to the difference between a vapor end point of 300° C. and a liquid end point of 360° C.

However, figure 4 does indicate that if arbitrary intermediate cutting points are taken, based on liquid temperature control, the fractions of distillate may be composed of constituents having widely different boiling points. For instance, if a liquid temperature cut is made at 225° C. (437° F.), the fraction below this temperature will contain material with a maximum boiling point in the case of the TC product of 125° C. (257° F.) and in the case of the TR product of 180° C. (356° F.), a spread of 55° C. Also, if a vapor temperature cut is made at 150° C., the spread between the TR and TP materials is 40° C. Therefore, it would seem that vapor temperature distillation control would be slightly the more preferable if it is desired to determine the character of the fractions obtained at various cutting temperatures, especially when comparison of

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[5] New Viscosimeter for Bitumens Has Extended Range, by E. O. Rhodes, E. W. Volkmann, and C. T. Barker. Engineering News-Record, vol. 115, no. 21, Nov. 21, 1935.

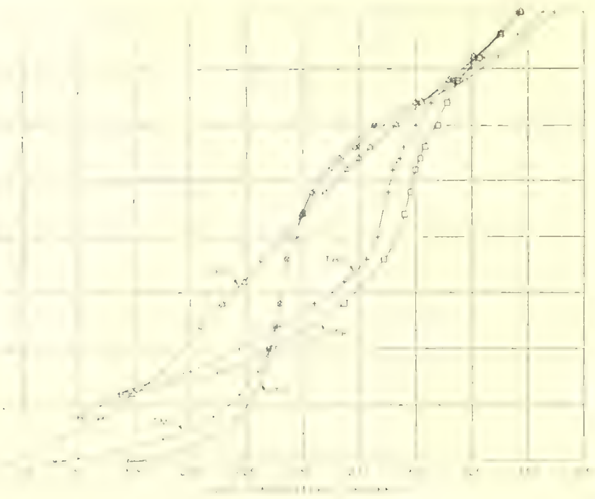

Figure 4.—Comparison of Liquid Temperature One-Fourth Inch Above Bottom of Flask and Vapor Temperature at Tubulature for Various Road Tars.

the distillates from materials of widely different composition is desired.

Similar tests on a few samples of liquid asphaltic materials of the slow-curing, medium-curing, and rapid-curing types gave similar results. The curves showing the relation between liquid and vapor temperatures were of different shape for the different types of materials and also for different materials of the same type. There was also the same general agreement between a vapor temperature of 300° C. and a liquid temperature of 360° C., the vapor temperature of 300° C. corresponding to a liquid temperature of 360° C. or less.

Having established that there is no wide difference between a vapor end point of 300° C. (572° F.) and a liquid end point of 360° C. (680° F.), the effect on the character of the residue obtained by pouring as required by A. S. T. M. method D 20–30 and by A. S. T. M. method D 402–34 T was determined. The results of tests made on residues poured after they had cooled below 125° C. (257° F.) and when the residues were poured immediately after a vapor temperature of 300° C. (572° F.) was reached, are given in table 8.

The difference in the percentage of volatile matter lost in pouring and cooling the residues by the two methods varied from 0.83 to 4.15 percent of the total sample for all the materials tested, with an average difference of 2.37 percent. The losses in volatile matter in A. S. T. M. method D 20–30 are unavoidable losses caused by retention of distillate in the condenser. The effect of the greater loss of volatile matter that occurs when residues are poured according to A. S. T. M. method D 402–34 T is shown by the harder consistency of the corresponding residues. The softening points of the residues poured immediately were from 2.3° to 21.1° C., with an average of 6.8° C., higher than those poured in the usual procedure for tars. The penetration values also show the greater hardness of the residues poured immediately, the decrease in penetration ranging from 0 to 120 with an average of 26.3. Due to this increase in hardness, the softening point values of six of the residues from the TC and TM grades of tar, were increased until they exceeded the maximum allowed by the Federal specifications.

When an asphalt has been blended with a naphtha to produce a liquid asphalt of the rapid-curing type, it has been found that by pouring the residue immediately after the end point is reached the penetration of the residue is in very close agreement with the penetration of the base asphalt used in producing the blend. However, no information on the consistency of the base materials in medium-curing and slow-curing liquid asphaltic products is obtainable, even with this method

Table 8.—*Effect of method of pouring distillation residues upon their properties*

Type of material	Identification	Total loss in distillation test			Loss of volatile matter during test			Softening point			Penetration at 25° C., 100 g, 5 sec.		
		A. S. T. M. D 20-30	A. S. T. M. D 402-34 T	Difference	A. S. T. M. D 20-30	A. S. T. M. D 402-34 T	Difference	A. S. T. M. D 20-30	A. S. T. M. D 402-34 T	Difference	A. S. T. M. D 20-30	A. S. T. M. D 402-34 T	Difference
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	° C.	° C.	° C.			
TC-1	7	35.90	37.29	1.39	0.75	1.58	0.83	45.0	54.0	9.0	38	21	17
	14	38.04	38.90	.86	.62	2.79	2.17	54.8	61.7	6.9	25	9	16
	20	32.06	35.64	3.58	.30	3.30	3.00	47.4	55.4	8.0	38	12	26
	24	34.35	37.95	3.60	33	2.58	2.25	45.2	54.4	9.2	50	13	37
TC-2	1	33.19	34.55	1.36	.33	2.59	2.26	44.6	50.1	5.5	38	30	8
	15	36.34	37.66	1.32	.56	2.44	1.88	55.6	62.7	7.1	20	8	12
	21	29.25	31.75	2.50	.34	2.94	2.60	50.8	57.0	6.2	27	8	19
	33	29.92	34.07	4.15	.38	2.84	2.46	37.0	58.1	21.1	138	36	102
TC-3	16	35.50	36.69	1.19	1.00	2.83	1.83	57.1	63.1	6.0	18	7	11
	25	31.89	34.15	2.26	.55	2.89	2.34	46.6	52.2	5.6	42	19	23
TC-4	3	29.10	31.82	2.72	.85	3.07	2.22	45.0	54.0	9.0	53	16	37
	17	34.78	35.44	.66	.57	2.65	2.08	60.4	64.4	4.0	12	5	7
TM-1	8	26.05	28.80	2.75	.07	1.96	1.89	41.0	48.4	7.4	71	39	32
	11	27.57	30.06	2.49	44	2.32	1.88	42.0	49.2	7.2	74	41	33
	18	33.42	34.59	1.17	1.27	3.40	2.13	59.4	64.1	4.7	15	6	9
	35	25.31	28.97	3.66	.00	4.15	4.15	39.6	48.2	8.6	97	36	61
TM-2	5	25.73	27.74	2.01	.65	2.56	1.91	46.1	52.5	6.4	46	18	28
	19	31.89	32.45	.56	.80	2.31	1.51	60.0	65.8	5.8	12	5	7
	26	23.40	26.07	2.67	.36	3.54	3.18	43.2	50.7	7.5	62	25	37
TR-1	9	27.75	29.82	2.07	.45	1.92	1.47	60.0	65.0	5.0	12	7	5
TR-2	6	25.90	28.33	2.43	.71	3.67	2.96	53.1	60.4	7.3	20	5	15
	10	25.52	27.78	2.26	.62	2.15	1.53	55.8	61.0	5.2	18	9	9
	27	25.45	27.36	1.91	.29	3.48	3.19	55.4	59.5	4.1	15	6	9
TH-1	2	19.80	21.89	2.09	.57	3.31	2.74	51.7	58.1	6.4	26	9	17
	12	15.54	16.58	1.04	.38	1.55	1.17	41.6	44.8	3.2	89	67	22
	32	11.12	15.71	4.59	31	3.68	3.37	33.1	39.7	6.6	218	98	120
	28	14.37	15.82	1.45	.48	3.12	2.64	47.0	52.8	5.8	43	21	22
TP-1	13	11.79	13.10	1.31	.19	1.49	1.30	49.0	54.0	5.0	38	22	16
TP-2	29	11.72	14.77	3.05	.32	3.68	3.36	49.6	56.0	6.4	30	10	20
[illegible]	4	13.20	15.63	2.43	.99	4.74	3.75	56.1	60.1	4.0	12	5	7
[illegible]	30	8.72	10.88	2.16	.31	3.57	3.26	51.8	56.8	5.0	25	12	13
	34	5.90	9.38	3.48	.18	3.42	3.24	44.1	54.4	10.3	71	13	58
Special	22	19.62	21.50	1.88	.00	2.31	2.31	58.5	61.6	3.1	15	6	9
	23	47.85	49.23	1.38	.48	2.80	2.32	39.1	52.7	13.6	84	26	58
	31	18.90	19.79	.89	.79	2.58	1.79	73.3	75.6	2.3	1	1	0

of pouring. Most road tars have tar pitches as bases which contain some volatile matter to 300° C. (572° F.) and it is doubtful if the true consistency of the base material can be approximated by either method of pouring the residue.

Liquid asphaltic materials have been classified according to the consistency of the residues from the D 402–34 T distillation test as follows: [6]

Group 1.—Liquid residue, float test less than 25 seconds at 122° F. (50° C.), nonhardening or extremely slow hardening.

Group 2.—Float residue, float test more than 25 seconds at 122° F. (50° C.) and penetration of more than 300 at 77° F. (25° C.), medium hardening.

Group 3.—Penetration residue, penetration less than 300 at 77° F. (25° C.), rapid hardening, the speed of hardening being dependent on the amount and volatility of the distillate.

Under the above classification, it will be seen from table 8 that all of the road tars included in this investigation, even if the softer consistencies of the residues obtained by the D 20–30 method of pouring are considered, are of the rapid-hardening type of bituminous material.

DISTILLATION RESIDUES HAD GOOD DUCTILITY AT NORMAL TEMPERATURES

For some time specifications for many asphaltic materials have included a ductility requirement as a means of control and as an indication of the adaptability of the products to particular uses. Asphaltic cements, and usually the distillation residues and asphaltic residues of liquid asphaltic materials, are required to show a certain ductility at 25° C. (77° F.) and for some purposes at lower temperatures such as 1.5° C. (34.7° F.) or 4° C. (39.2° F.). While the ductility test has been criticised as not being a good measure of the resistance to the stresses to which asphalts in road surfaces are subjected, its use as a laboratory test for these materials is widespread.

If the asphalts used in particular types of road construction must meet a ductility requirement, it is logical that tar products for similar use should also meet a ductility requirement. At the present time the only tars that are tested for ductility are the tar pitches used in roof construction and for water-proofing structures. Few data are available regarding the ductility of road tars. In order to obtain as much information as possible on the physical properties of these tar products, the residues obtained in the standard A. S. T. M. D 20–30 distillation test were tested for ductility.

The ductility tests were made on each distillation residue at several temperatures in order to obtain some idea of its temperature-ductility curve. The tests were made at 10° C., 15° C., 20° C., and 25° C. and the results are given in table 9.

In order to compare the results of the ductility test with the other tests made on the distillation residues, the data in table 9 have been grouped according to the index shown in table 10. An index of 1 represents the most ductile residue at low temperature and an index of 7 the least ductile.

The ductility index and the other test results on the distillation residues are given in table 11. It is evident that consistency as measured by the softening point or penetration is related to the ductility of these tar pitches. At a given temperature, the harder the material the less ductility it possesses. It is indicated that the free carbon content also influences the ductility. In general, as the percentage of free carbon increases the ductility decreases.

TABLE 9.—*Ductilities of the A. S. T. M. D 20–30 distillation test residues*

Type of material	Identification	At 25° C.	At 20° C.	At 15° C.	At 10° C.
		Cm	*Cm*	*Cm*	*Cm*
TC-1	7	83	90	55	1.5
	11	74	66	0.25	0
	20	110+	110+	110+	0
	21	110+	110+	110+	0
TC-2	1	110+	110+	110+	0
	15	73	66	0	0
	21	110+	110+	0	0
	33	110+	110+	110+	110+
TC-3	16	54	0	0	0
TC-4	25	110+	110+	110+	0
	3	110+	110+	110+	0
TM-1	17	52	0	0	0
	8	48	65	66	92
	11	73	55	67	110+
	18	76	0	0	0
TM-2	35	110+	110+	110+	110+
	5	110+	110+	110+	0
	19	36	0	0	0
	26	110+	110+	110+	0
TR-1	9	43	0	0	0
TR-2	6	110+	0.75	0	0
	10	77	1.5	0	0
	27	110+	70	0	0
TH-1	2	110+	110+	0	0
	12	53	10	71	110+
	32	110+	110+	110+	110+
	28	110+	81	0	0
TP-1	13	52	60	7.5	0
TP-2	29	110+	110+	0.25	0
TP-4	4	110+	0.5	0	0
TP-6	30	110+	110+	0	0
Special	34	110+	110+	110+	0.75
	22	100+	0.25	0	0
	23	110+	110+	110+	110+
	31	0	0	0	0

TABLE 10.—*Ductility index for distillation residues of tars*

Index	Ductility (cm)	
1	90+ at 10° C.	----------
2	55–110+ at 15° C.	0–1½ at 10° C.
3	110+ at 20° C.	0–¼ at 15° C.
4	52–110+ at 25° C.	60–81 at 20° C.
5	110+ at 25° C.	¼–¾ at 20° C.
6	45–79 at 25° C.	0–1½ at 20° C.
7	0 at 25° C.	----------

TABLE 11.—*Range in test values of the A. S. T. M. D 20–30 Distillation test residues grouped according to ductility index*

Ductility index	Softening point			Penetration at 25° C.			Free carbon		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
	° C.	*° C.*	*° C.*				*Per-cent*	*Per-cent*	*Per-cent*
1	33.1	42.0	39.1	71	218	110	1.3	11.7	8.3
2	43.2	47.4	45.2	38	71	[illegible]	9.1	13.0	11.4
3	49.6	51.8	51.0	25	30	27	13.0	18.7	15.5
4	47.0	55.6	52.4	15	43	28	11.4	17.5	13.3
5	53.1	58.5	55.9	12	20	16	20.3	30.1	23.8
6	55.8	60.4	58.8	12	18	15	11.4	14.3	13.3
7	...	...	73.3	...		[illegible]		...	20.1

EFFECTS OF EXPOSURE ON TAR PRODUCTS HAVE BEEN STUDIED EXTENSIVELY

W. H. Flood [7] has stated that the great majority of asphalts of the 40–50, 50–60 and 60–70 grades used in road construction have ductility values beyond the limits of the ductility machine. He has shown that materials meeting these penetration grades have ductility values at 60° F. (15.5° C.) averaging from 10.5

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[6] Rationalization and Simplification of Test Requirements for Liquid Asphaltic Materials, by E. F. Kelley and Prevost Hubbard. PUBLIC ROADS, vol. 13, [illegible] August 1932.

[7] Ductility at Low Temperatures. [illegible] Proceedings of the Association of Asphalt Paving Technologists.

centimeters to 75.4 centimeters, and at 39.2° F. (4° C.) values averaging from 3.2 centimeters to 4.8 centimeters for the different consistency ranges and sulphur contents. When these figures are compared to the results obtained on the tar residues having a ductility index of 2 and a range in penetration of 38 to 71, it is seen that tars have a more rapid and abrupt loss of ductility when the test temperature is reduced than do asphalts. This is the result, no doubt, of the greater susceptibility of tars to temperature change, causing a more rapid transition of these materials from a semisolid to a solid state. The tests show that nearly all of the residues have good ductility at 25° C., but, in general, this ductility is rapidly lost when the temperature of test is reduced.

In recent years much thought has been given to the changes that take place in bituminous materials under service conditions. The initial bonding strength of a tar product when applied to the road surface is developed in different ways, depending not only on the type of original material but also on the way it is used and the climatic conditions to which it is subjected. All grades of road tar lose a certain amount of volatile matter. This tends to stiffen or harden the material. After the initial bond has been developed, either by evaporation, cooling, or a combination of both, certain hardening takes place because of inherent changes brought about by weathering.

Early investigators have done much work to substantiate these facts. Hubbard and Reeve[8] published a paper in 1913 regarding the effect of exposure on bitumens. Included in this investigation were three tar products; namely, a refined coal tar, a refined water-gas tar, and a refined mixture of coal tar and water-gas tar. The authors made the following conclusion:

> It is apparent from these results that the hardening of all bitumens upon exposure is not due to loss by volatilization of the lighter constituents, alone, although in tars such loss is probably responsible to a considerable degree for the hardening of these products. The hardening of petroleum and asphalt products is undoubtedly due to oxidation which proceeds slowly at comparatively low temperatures but increases at higher temperatures. It seems probable that oxidation also plays a part in the hardening of tars although the preceding data does not absolutely prove this fact.

Later Reeve and Lewis[9] substantiated and amplified the previous data which showed that upon exposure bituminous materials undergo changes caused by factors other than loss of the more volatile constituents. They also showed that the insoluble organic matter in the bitumens they examined increased materially in a closed oven where the chances of oxidation are reduced to a minimum. The authors stated that while oxidation plays a part in the changes that occur, they were led to the conclusion that polymerization and intermolecular reactions induced by heat, and possibly increased by the action of light, are also very largely responsible for such changes, in addition to those accounted for by simple evaporation.

Reeve and Anderton,[10] while noting that the action of air and sun upon bitumens in their original state is probably quite different than might be expected in actual service, concluded that: (1) Upon exposure tar products harden to a much greater extent than could be attributed to the loss of volatile matter alone; (2) changes are accompanied by formation of material insoluble in carbon disulphide; (3) the development of free carbon was greater in water-gas tar than in coal tar; and (4) the comparative consistency of the residues from distillation to a single arbitrary end temperature did not represent the relative behavior of tars in service.

More recent investigations [11] [12] by the Bureau on the effects of exposure on liquid asphaltic materials of the slow-curing, medium-curing, and rapid-curing types have indicated that many materials that have similar characteristics as determined by the usual laboratory tests behave quite differently when exposed in thin films or in mixtures with a standard aggregate.

Exposure tests on the tars were made in boxes of the same type as were used in previous investigations of the Bureau. A sketch of the box is shown in figure 5. The boxes were constructed of ¾-inch wood, the interior dimensions being 30 by 24 by 3 inches. A hole in the center of the bottom of each box served to admit a stream of clean, dry air to carry away any collected vapors. Outlets for the air were made by cutting slots in the sides of the boxes. These were packed with cotton batting to prevent the entrance of dust. Plate glass, resting on thin strips of felt placed along the edges of the boxes, served as covers.

Three 50-cubic centimeter samples of each tar were placed in seamless flat tins, 5½ inches in diameter and ⅝ inch deep. This amount of material gave a uniform film thickness of ⅛ inch. The exposure boxes containing the three sets of exposure samples, one each for 5-, 10-, and 15-week periods, are shown in figure 6.

ULTIMATE LOSS ON EXPOSURE CLOSELY APPROXIMATED LOSS IN A.S.T.M. D 20-30 DISTILLATION TEST

The samples were placed in the exposure boxes on June 15, 1933. During the following 15 weeks the hourly temperatures within the boxes were recorded daily from 9 a. m. to 4 p. m. The maximum temperature reached during this time was 196° F. (91° C.) occurring on a clear day with a maximum of sunshine. On cloudy days the temperature within the boxes was the same as the outside air temperature. The average maximum daily air temperature was 85° F. (30° C.). As determined from United States Weather Bureau reports for the period of exposure, the samples from the 5-, 10-, and 15-week periods were subjected to 333, 611, and 866 hours of sunlight, respectively.

The samples tested at the end of 15 weeks of exposure were weighed at various intervals to determine the loss of volatile matter at all intermediate periods except the 35-day and 70-day periods (5 and 10 weeks). The losses at these two periods were determined on the samples removed for test at that time, so that the percentage of loss obtained could be correlated accurately with the test values on the residues. This procedure, no doubt, accounts for variations in losses between the 35- and 70-day tests that appear to indicate gains in weights rather than continued losses. The percentages of loss at different periods are tabulated in table 12 and the average for each grade of material is shown graphically in figure 7.

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[8] The Effect of Exposure on Bitumens, by Prevost Hubbard and C. S. Reeve Industrial and Engineering Chemistry, vol. 5, no. 1, January 1913.

[9] The Effect of Exposure on Some Fluid Bitumens, by C. S. Reeve and R. H Lewis. Journal of Industrial and Engineering Chemistry, vol. 9, no. 8, August 1917

[10] The Effect of Exposure on Tar Products, by C. S Reeve and B. A. Anderton Journal of Franklin Institute, vol. 182, no. 10, October 1916.

[11] A Study of Some Liquid Asphaltic Materials of the Slow-Curing Type, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol 15, no 4, June 1934.

[12] Further Studies of Liquid Asphaltic Materials, by R. H. Lewis and W. O'B. Hillman. PUBLIC ROADS, vol 16, no 6, August 1935.

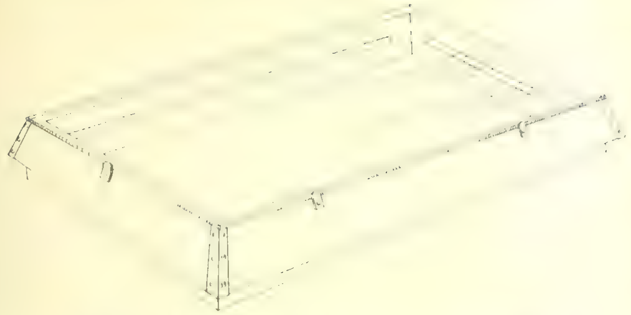


Figure 5.—Box Used in Exposure Tests.

Table 12.—*Rate of loss of volatile matter in thin-film exposure of road tars*

Type of material	Identification	Time of exposure in days							
		2	8	15	22	35	50	70	105
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
TC-1	7	23.9	31.4	32.4	32.9	33.2	33.5	34.4	34.0
	14	24.1	31.5	31.9	32.7	33.1	33.2	33.7	33.6
	20	22.3	29.5	31.2	32.9	33.9	33.9	33.3	34.5
	24	22.9	30.5	32.8	34.9	35.3	36.0	35.3	36.3
TC-2	4	19.2	26.6	28.7	30.9	31.4	31.8	31.1	32.3
	15	21.5	30.1	30.3	31.0	30.5	31.4	30.7	31.7
	21	18.7	26.1	27.4	29.4	29.2	30.1	29.1	30.7
	33	17.2	24.3	27.3	30.4	30.8	31.6	32.7	30.5
TC-3	16	21.6	29.2	29.3	29.9	28.8	30.3	29.5	30.9
	25	19.2	26.9	28.6	30.6	31.6	32.4	31.3	32.7
TC-4	3	17.0	24.1	25.9	27.4	26.2	28.5	23.4	28.6
	17	21.6	26.8	27.0	27.5	26.0	28.2	27.1	28.4
TM-1	8	13.5	22.2	23.1	24.9	23.1	25.5	25.4	26.3
	11	11.9	20.3	22.7	25.0	23.6	25.8	25.2	26.7
	18	20.9	24.6	24.9	25.3	24.3	25.9	26.5	26.4
	35	13.0	19.9	21.3	23.6	25.1	24.8	25.3	25.6
TM-2	5	13.3	19.3	20.9	22.4	22.4	23.7	23.3	24.0
	19	17.6	22.4	22.8	23.4	23.1	24.0	23.7	24.3
	26	11.1	17.9	20.0	22.7	23.0	25.0	24.9	25.4
TR-1	9	16.8	21.3	21.5	22.1	21.5	22.8	22.4	23.3
TR-2	6	14.7	20.1	21.2	22.4	22.0	22.8	22.3	23.5
	10	13.6	19.1	19.5	19.8	19.8	20.6	20.0	21.3
	27	15.3	19.4	20.9	22.1	21.2	22.6	22.6	22.7
TH-1	2	7.6	12.5	13.7	15.2	14.2	15.8	15.4	16.2
	12	4.1	8.4	11.0	13.4	12.3	14.1	14.6	14.7
	32	2.0	8.2	10.8	14.3	15.0	18.2	19.9	19.7
	28	4.2	8.8	10.7	12.8	12.6	14.0	15.0	14.5
TP-1	13	2.3	5.3	7.3	8.3	7.1	8.9	9.4	9.9
TP-2	29	2.7	6.4	7.9	9.8	10.4	11.4	10.6	11.7
TP-4	1	2.7	5.3	6.4	7.7	7.4	8.2	7.6	8.7
TP-6	30	1.2	4.3	5.3	6.5	6.8	7.5	7.1	8.2
	34	.7	3.4	4.8	7.2	8.7	9.7	9.6	10.5
Special	22	7.3	12.2	13.5	14.9	14.2	15.7	15.3	16.0
	23	29.9	41.4	44.4	45.4	46.6	46.4	48.4	46.3
	31	2.9	6.2	6.4	7.0	6.7	7.8	6.0	8.1

During exposure a skin was formed on the surface of the samples, the thickness of the skin increasing as the loss of the volatile constituents increased. The thickness of the skin had increased noticeably by the end of each exposure period, the depth of softer material on the bottom of the pan being correspondingly reduced. Photographs showing the condition of the film surfaces after 15 weeks exposure are shown in figures 8 to 11 inclusive.

It will be noticed from table 12 and figure 7 that all of the tars lost weight rapidly at first and then more slowly as the time of exposure increased. Based on the loss after 15 weeks, the maximum loss in 2 days was 79.2 percent, the minimum 6.7, and the average loss for the 32 tars meeting some specification was 51.7 percent. In 15 days the maximum loss was 95.6, the minimum 45.7, and the average 84.1 percent. Beyond the 15-day period all samples lost weight very slowly. At the end of the 50-day period the average loss for all samples was 97.4 percent of the loss at 15 weeks. The cold-application tars showed a much higher rate of loss than did the hot-application tars. At the end of 8 days the former showed an average loss of 86.1 percent of their ultimate loss, while the nine hot tars required a period of 22 days to show an average loss of 83.2 percent.

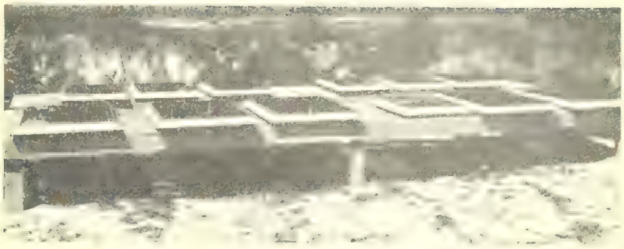


Figure 6.—Exposure Boxes Containing Tar Samples and Hubbard-Field Specimens During an Exposure Test

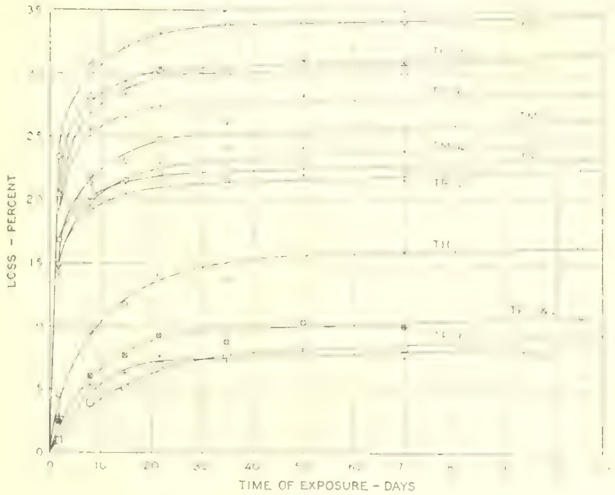


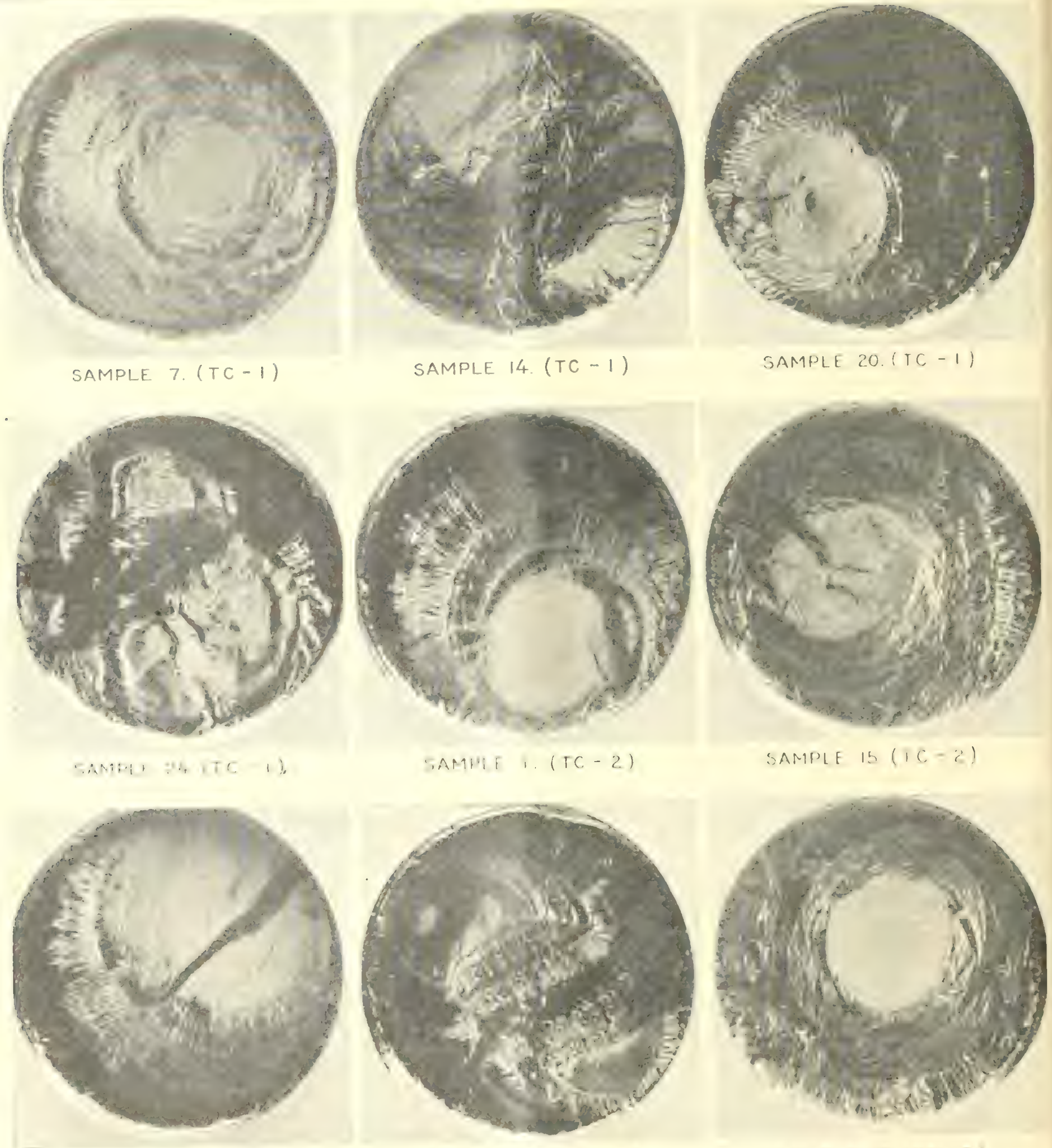
Figure 7.—Rate of Loss in Thin-Film Exposure of Various Road Tars (Values Are Averages for Each Grade).

In order to make comparisons of the characteristics developed by 5-, 10-, and 15-week exposures and by the distillation test, the respective residues were subjected to the same tests. These data are shown in table 13.

EXPOSURE RESIDUES WERE HARDER AND DEVELOPED MORE FREE CARBON THAN DISTILLATION RESIDUES

The average total loss in the distillation test, A. S. T. M. D20–30, for the 32 tars that substantially met the Federal specifications was 25.3 percent as compared to the average loss of the same samples for 5, 10, and 15-week exposure periods of 22.3, 23.2, and 24.0 percent, respectively. Since the average total loss in the distillation test, when the residue was poured immediately, was 27.5 percent for these same samples, it is seen that the ultimate loss as determined at the end of the 15-week period was in closer agreement with the loss obtained in the standard method of distilling tar products. Figure 12 compares the total loss in the distillation test, A. S. T. M. D20–30, with the loss occurring in thin films at the end of 15 weeks of exposure. Samples 32 and 34 were the only tars to show an appreciably greater loss under exposure than occurred in the distillation test. All other materials had losses approximately equal to or less than the losses in distillation.

Although the loss of volatile matter in 5 weeks was practically equal to or less than the loss in the distillation test, except for samples 32 and 34, all the residues from this period except for samples, 9, 10, 22, and 31, had penetrations equal to or lower and softening points



SAMPLE 7. (TC - 1) SAMPLE 14. (TC - 1) SAMPLE 20. (TC - 1)

SAMPLE 24 (TC - 1) SAMPLE 1. (TC - 2) SAMPLE 15 (TC - 2)

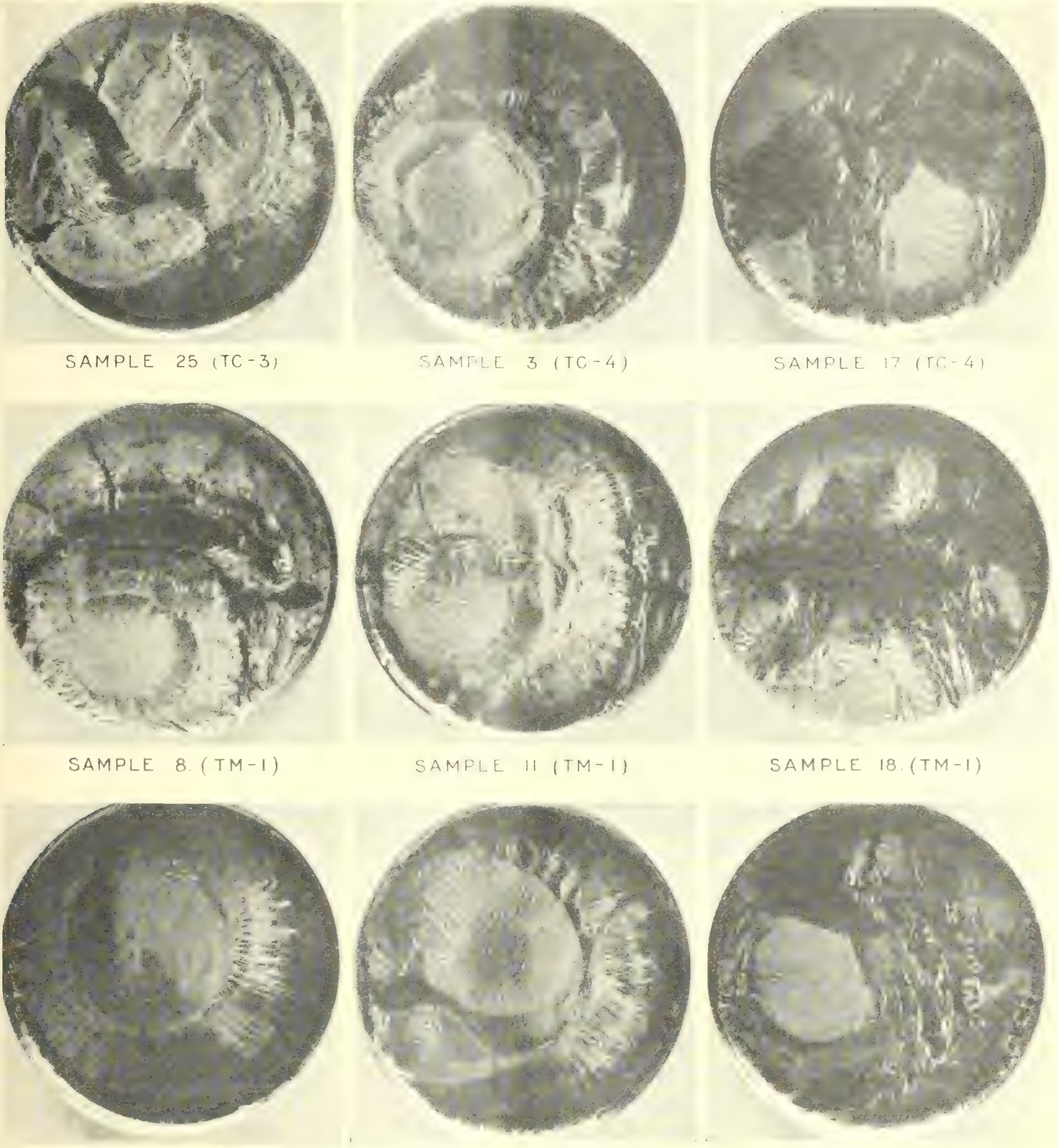
SAMPLE 21. (TC - 2) SAMPLE 33 (TC - 2) SAMPLE 16 (TC - 3)

FIGURE 8.—APPEARANCE OF SURFACES OF TAR SAMPLES AFTER 15 WEEKS OF EXPOSURE. THE FIGURES IN PARENTHESES ARE THE FEDERAL SPECIFICATION GRADES TO WHICH THE SAMPLES CONFORM. THE CENTERS OF THE SPOTS ON SAMPLES 7 AND 1 WERE HIGHLY CARBONIZED. ALL OF THE OTHER SAMPLES WERE SLIGHTLY CARBONIZED.

equal to or higher than the corresponding distillation residues.

The greatest difference in penetration occurred in the exposure residues of samples 23, 24, 26, 32, 33, 34, and 35, their penetrations ranging from one-ninth to one-twenty-fifth of the penetrations of their corresponding distillation residues. At the end of 10 weeks only the residue of sample 31 had a softening point appreciably lower than that of its distillation residue. The softening point of the exposure residue of sample 22 was approximately the same as that of its distillation residue. After 15 weeks of exposure all residues, except that of sample 31, were considerably harder than their corresponding distillation residues.

A comparison of the softening points and penetrations of the distillation residues and the 15-week exposure



SAMPLE 25 (TC-3) SAMPLE 3 (TC-4) SAMPLE 17 (TC-4)

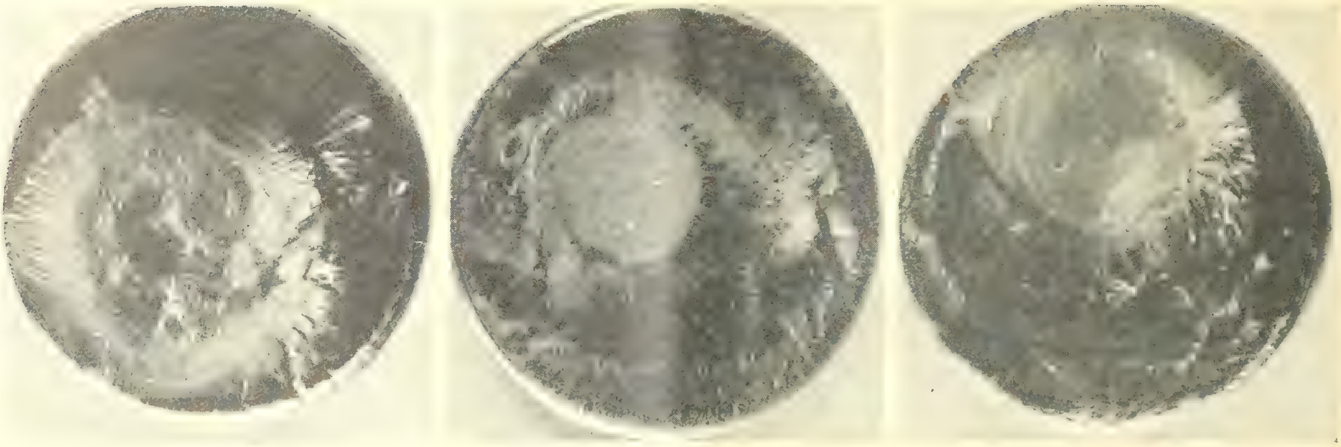
SAMPLE 8. (TM-1) SAMPLE 11 (TM-1) SAMPLE 18. (TM-1)

SAMPLE 35 (TM-1) SAMPLE 5. (TM-2) SAMPLE 19. (TM-2)

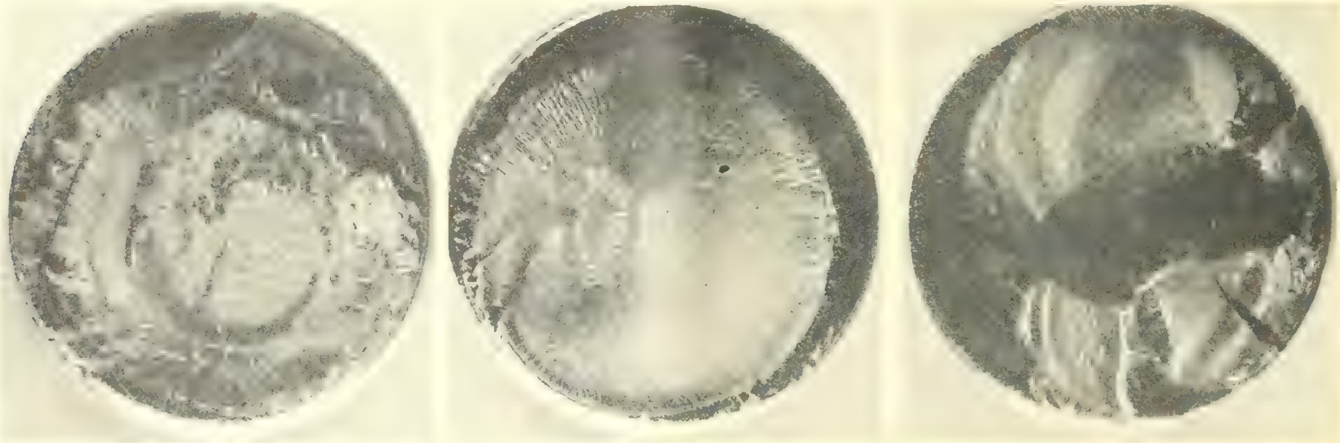
FIGURE 9.—APPEARANCE OF SURFACES OF TAR SAMPLES AFTER 15 WEEKS OF EXPOSURE. THE FIGURES IN PARENTHESES ARE THE FEDERAL SPECIFICATION GRADES TO WHICH THE SAMPLES CONFORM. THE CENTER OF THE SPOT ON SAMPLE 8 WAS HIGHLY CARBONIZED AND THE ROUGH AREAS ON SAMPLE 11 WERE CARBONIZED. ALL OF THE OTHER SAMPLES WERE SLIGHLTY CARBONIZED, AND IN ADDITION SAMPLE 5 WAS FLUORESCENT AND SAMPLE 25 WAS PARTIALLY FLUORESCENT.

residues substantiates the conclusion of Reeve and Anderton that the comparative consistencies of the residues from distillation to a single arbitrary temperature do not represent the relative behavior of tars in service. The average softening point of the distillation residues of samples 7, 14, 20, and 24 meeting TC-1 specification was 48.1° C., and the average softening point of the residues after 15 weeks of exposure was 74.5° C. The distillation residues of the five TP products, samples 4, 13, 29, 30, and 34, had an average softening point of 50.1° C., but the average softening point of their exposure residues was slightly under 65° C.

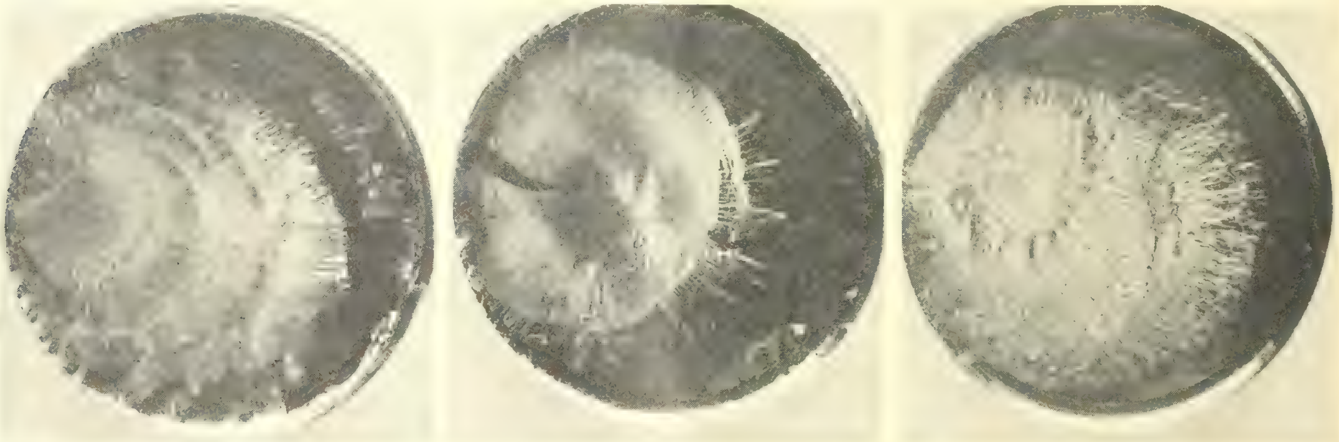
Early investigators, as previously mentioned, noted that tar products on exposure developed considerable



SAMPLE 26. (TM-2) SAMPLE 9. (TR-1) SAMPLE 6. (TR-2)



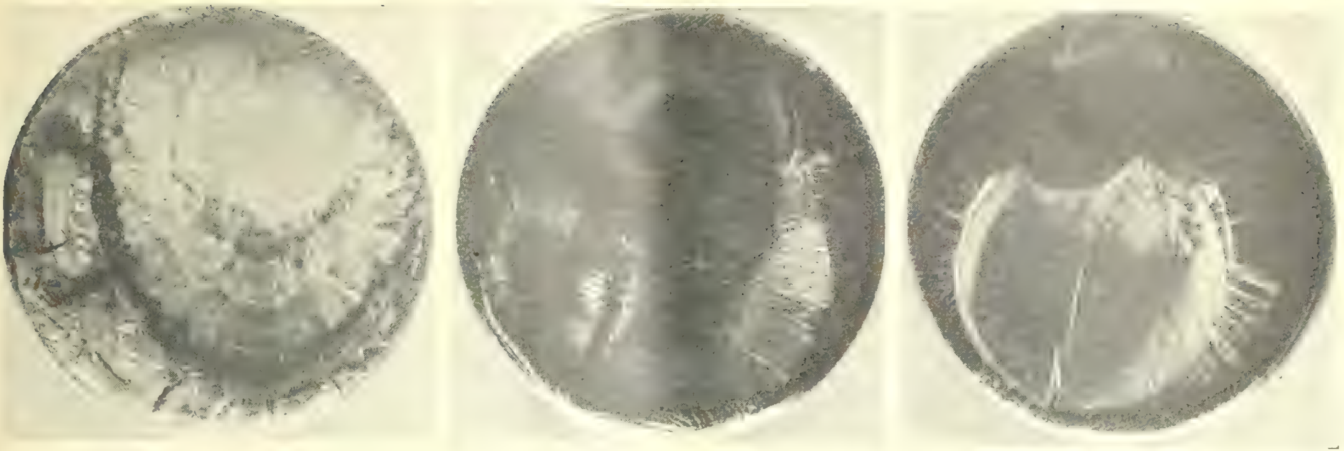
SAMPLE 10 (TR-2) SAMPLE 27. (TR-2) SAMPLE 2. (TH-1)



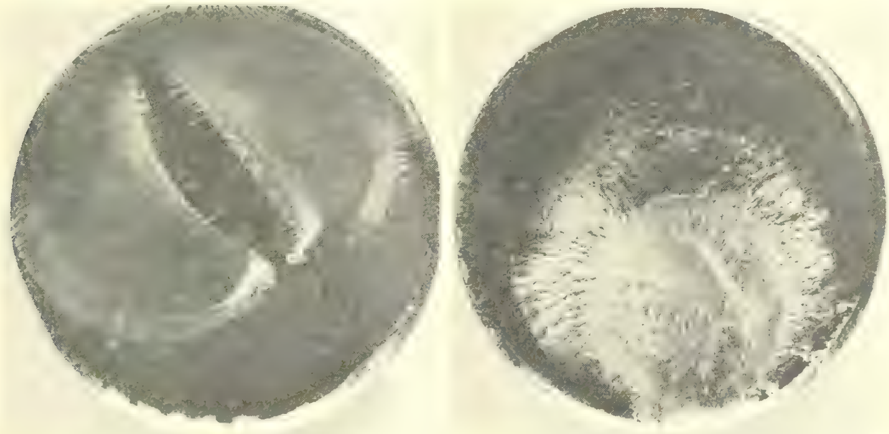
SAMPLE 12. (TH-1) SAMPLE 28. (TH-1) SAMPLE 32. (TH-1)

Figure 10.—Appearance of Surfaces of Tar Samples After 15 Weeks of Exposure. The Figures in Parentheses Are the Federal Specification Grades to Which the Samples Conform. The Concentric Circles on Sample 12 Show Increasing Carbonization Toward the Center, and the Spots on Samples 9 and 10 Were Carbonized. All of the Other Samples Were Slightly Carbonized, and in Addition, Samples 26 and 27 Were Fluorescent.

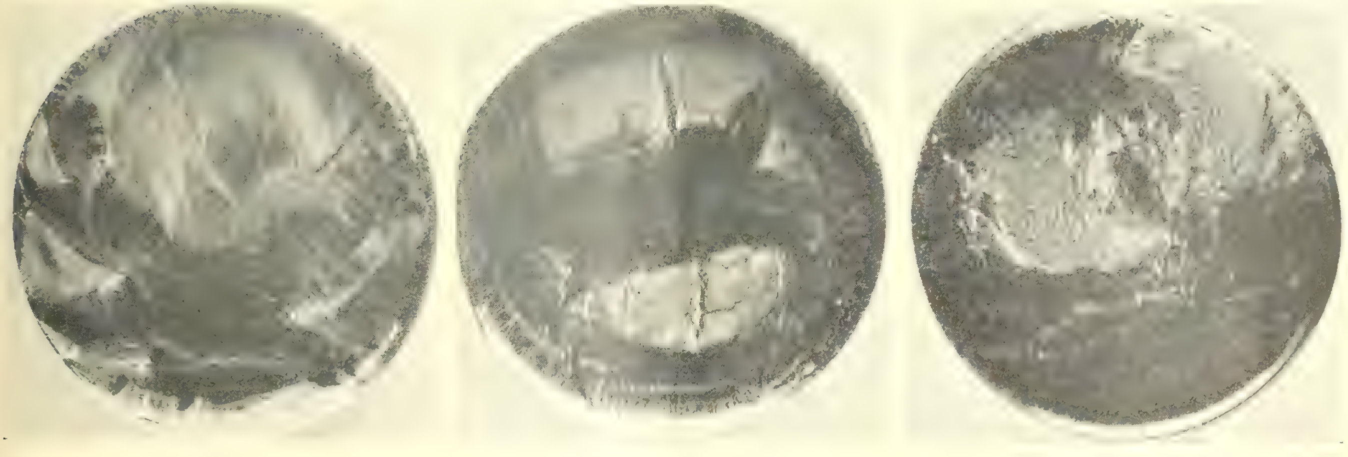
quantities of free carbon. In order to see if this production of organic material was more pronounced under exposure conditions than under the accelerated laboratory heat test (the distillation test), determinations of solubility in carbon disulphide were made on all residues thus obtained. By expressing the percentage of free carbon in any residue in terms of the weight of the original material, then dividing by the percentage of free carbon in the original material and multiplying by 100, the result is the index of increase in free carbon. An index of 100 indicates that no increase nor decrease has taken place. The indexes of increase in free carbon for the various residues are given in table 14.



SAMPLE 13. (TP-1) SAMPLE 29 (TP-2) SAMPLE 4. (TP-4)



SAMPLE 30. (TP-6) SAMPLE 34 (TP-6)



SAMPLE 22 (SPECIAL MATERIAL) SAMPLE 23 (SPECIAL MATERIAL) SAMPLE 31 (SPECIAL MATERIAL)

Figure 11. Appearance of Surfaces of Tar Samples After 15 Weeks of Exposure. The Figures in Parentheses Are the Federal Specification Grades to Which the Samples Conform. The Center of the Spot on Sample 13 Was Carbonized; Samples 34, 23, and 31 Were Slightly Carbonized; and All of the Other Samples Were Very Slightly Carbonized. In Addition, Samples 29 and 30 Were Slightly Fluorescent.

LOSS OF VOLATILE MATTER, OXIDATION, AND POLYMERIZATION CAUSE CHANGES UPON EXPOSURE

This table indicates that the distillation residues of samples 6, 7, 8, 9, 10, 11, 12, 13, and 23 and the residues from exposure of sample 7 at 5 and 10 weeks and of sample 9 at 15 weeks had indexes of increase of less than 100. These apparent decreases in free carbon may, in the majority of cases, result from slight inaccuracies in the carbon-disulphide solubility tests. In the case of sample 23, repeated check tests on both the original material and the distillation residue indicated that the free carbon content of this material was greatly reduced

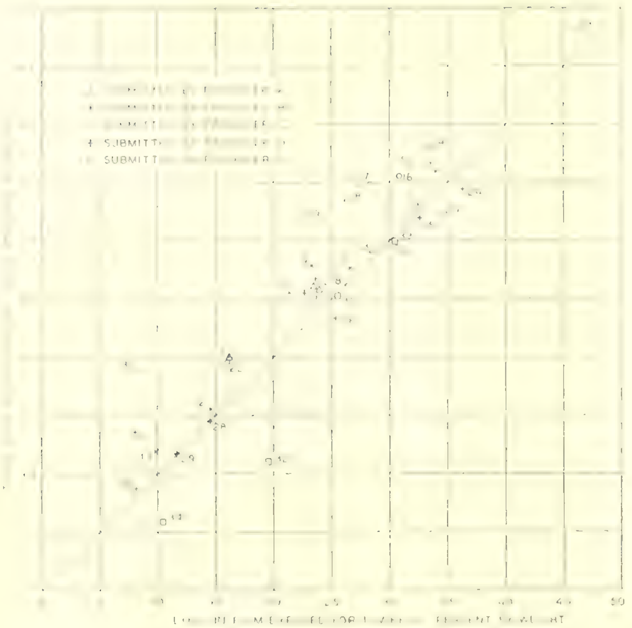


FIGURE 12.—COMPARISON OF THE 15-WEEK EXPOSURE LOSS WITH THE TOTAL LOSS IN DISTILLATION.

during distillation. This sample under exposure rapidly developed material insoluble in carbon disulphide. For all materials, except samples 7 and 31, the index of increase in free carbon is least in the distillation residues and greatest in the 10- or 15-week exposure residues.

TABLE 14.—*Index of increase in free carbon for various residues*

Type of material	Identification	Distillation residue	Exposure residues		
			5 weeks	10 weeks	15 weeks
		Percent	*Percent*	*Percent*	*Percent*
TC-1	7	92	79	93	116
	14	116	131	154	184
	20	172	262	294	328
	24	126	194	210	220
TC-2	1	100	152	169	169
	15	120	139	162	155
	21	170	258	287	302
	33	121	216	245	339
TC-3	16	122	140	163	172
	25	122	185	190	205
TC-4	3	103	133	156	163
	17	130	148	162	172
TM-1	8	96	118	126	129
	11	93	120	130	133
	18	125	148	166	178
	35	123	189	202	240
TM-2	5	104	138	142	152
	19	126	145	164	168
	26	119	176	193	201
TR-1	9	88	109	110	94
TR-2	6	93	109	113	117
	10	93	112	111	120
	27	116	132	143	145
TH-1	2	101	122	122	128
	12	97	120	134	131
	32	112	191	205	237
	28	121	153	169	173
TP-1	13	98	119		129
TP-2	29	120	144	149	161
TP-4	4	112	121	118	127
TP-6	30	113	132	136	150
	34	110	162	176	189
Special	22	115	118	122	127
	23	14	210	188	214
	31	128	123	131	141

As measured by the softening point, the hardness of the 5-week exposure residues of samples 1, 20, 23, 24, 25, 26, 32, 33, 34, and 35 exceeded the hardness of their distillation residues by the greatest amounts, the difference in softening points ranging from 14.4° C. to 26.4° C. The softening points of the 15-week exposure residues of these same materials exceeded the softening points of the distillation residues by amounts ranging from 21.9° C. to 41.4° C. With the exception of sample 21, the difference between the index of increase in free carbon for the exposure and distillation residues was also greatest for these materials. For the 5-week

TABLE 13.—*Results of laboratory tests on distillation and exposure residues*

Type of material	Identification	Distillation residue (A. S. T. M. D 20-30)				5-week exposure residue				10-week exposure residue				15-week exposure residue			
		Total loss	Penetration at 25° C., 100, g., 5 sec.	Softening point	Free carbon	Loss	Penetration at 25° C., 100, g., 5 sec.	Softening point	Free carbon	Loss	Penetration at 25° C., 100, g., 5 sec.	Softening point	Free carbon	Loss	Penetration at 25° C., 100, g., 5 sec.	Softening point	Free carbon
		Percent		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*	*Percent*		*°C.*	*Percent*
TC-1	7	35.90	38	45.0	11.7	33.2	15	58.0	9.8	34.4	5	69.4	11.6	34.0	2	73.3	14.4
	14	38.04	25	54.8	11.4	33.1	13	61.0	11.9	33.7	-----	69.2	14.1	33.6	2	74.3	16.9
	20	32.06	38	47.4	11.9	33.9	6	62.9	18.6	33.3	2	68.7	20.7	34.5	1	74.2	23.5
	24	34.35	50	45.2	12.6	35.3	7	66.7	19.8	35.3	-----	70.8	21.4	36.3	1	76.3	22.8
TC-2	1	33.19	38	41.6	9.1	31.4	9	59.3	13.5	31.1	5	66.7	15.0	32.3	2	71.9	15.2
	15	36.34	20	55.6	12.2	30.5	19	57.9	12.9	30.7	7	65.0	15.1	31.7	4	70.1	14.8
	21	29.25	27	50.8	13.0	29.2	6	61.1	19.6	29.1	-----	66.8	21.8	30.7	1	75.2	23.5
	33	29.92	138	37.0	6.6	30.8	7	59.4	11.8	32.7		67.3	13.8	30.5	2	71.5	18.6
TC-3	16	35.50	18	57.1	12.8	28.8	16	59.5	13.4	29.5	6	68.0	15.7	30.9	3	75.9	17.0
	25	31.89	42	46.6	12.9	31.6	[illegible]	64.9	19.4	31.3		67.3	19.9	32.7	1	74.2	22.0
TC-4	3	29.10	53	45.0	11.2	26.2	12	56.9	13.5	23.4	2	68.8	15.3	28.6	2	71.3	17.1
	17	34.78	12	60.4	13.8	26.0	17	59.0	13.6	27.1	-----	68.5	15.3	28.4	-----	74.2	16.6
TM-1	8	26.05	71	41.0	11.2	23.1	31	51.3	13.4	25.4		62.9	14.7	26.3	5	66.4	15.2
	11	27.57	74	42.0	11.0	23.6	35	50.2	13.5	25.2	15	59.3	14.9	26.7	6	65.3	15.6
	18	33.42	15	59.4	13.6	24.3	15	60.0	14.3	26.5	5	70.6	16.5	26.4	2	74.9	17.6
	35	25.31	97	39.6	7.8	25.1	9	57.5	11.9	25.3		61.6	12.7	25.6	4	64.5	15.2
TM-2	5	25.73	46	46.1	11.4	22.4	16	54.5	14.6	23.3		61.1	15.1	24.0	3	65.4	16.4
	19	31.89	12	60.0	13.7	23.1	14	59.7	13.9	23.7	8	65.7	15.8	24.3	4	68.4	16.4
	26	23.10	62	43.2	13.0	23.0	7	60.0	19.2	24.9		67.7	21.6	25.4	2	71.8	22.6
TR-1	9	27.75	12	60.0	14.3	21.5	25	55.5	16.3	22.4		62.9	16.6	23.3	6	68.0	14.1
TR-2	6	25.90	20	53.1	20.3	22.0	12	57.8	22.5	22.3	7	63.1	23.6	23.5	3	67.5	24.7
	10	25.52	18	55.8	11.4	19.8	27	54.0	12.8	20.0	10	59.5	12.8	21.3	6	67.0	14.0
	27	25.45	15	55.4	17.5	21.2	10	58.3	18.9	22.6		65.1	20.9	22.7	2	66.4	21.2
TH-1	2	19.80	26	51.7	18.7	14.2	15	56.0	21.1	15.4	4	64.1	21.4	16.2	2	67.4	22.7
	12	15.54	89	41.6	11.7	12.3	19	47.6	13.9	11.6	18	57.6	15.9	14.7	15	59.0	15.7
	32	11.12	218	33.1	8.6	15.0	16	53.0	15.3	19.9	-----	65.7	17.4	19.7	2	68.7	20.1
	28	14.37	43	47.0	13.7	12.6	13	57.0	16.9	15.0		64.7	19.3	14.5	2	65.2	19.7
TP-1	13	11.79	38	49.0	11.9	7.1	41	49.3	13.7	9.4	11	61.4	------	9.9	8	63.4	15.2
TP-2	29	11.72	30	49.6	15.2	10.4	5	59.9	18.0	10.6		63.1	18.7	11.7	3	66.6	20.4
TP-4	4	13.20	12	56.1	21.1	7.4	15	56.4	21.4	7.6	8	60.7	21.0	8.7	2	64.0	22.9
TP-6	30	8.72	25	51.8	15.1	6.8	12	56.5	17.3	7.1		59.5	17.9	8.2	4	64.0	19.9
	34	5.90	71	41.1	9.2	8.7	5	58.5	14.0	9.6		62.9	15.4	10.5	2	66.0	16.6
Special	22	19.62	15	58.5	30.1	14.2	10	50.0	29.0	15.3		57.6	30.3	16.0	5	63.0	31.9
	23	47.85	81	39.1	1.3	16.6	6	65.5	19.6	18.1		77.6	18.2	46.3	1	80.5	20.0
	31	18.90	1	73.3	20.1	6.7	12	51.7	16.7	6.0		59.4	17.7	8.1	3	68.5	19.5

exposure residues the difference ranged from 52 to 196 and for the 15-week exposure residues the difference ranged from 69 to 218.

It was shown by Reeve and Anderton [10] that water-gas tars low in free carbon increased in free-carbon content to a much greater extent than coal tars high in free carbon when exposed under conditions comparable to those of this investigation. Because of the large number of blended tars and the wide range in consistency of the materials covered in this study, the relations between free carbon in the original materials and the free-carbon content of the residues after exposure only indicate a general trend that the lower the free-carbon content of the original material the higher the index of free carbon in the exposed residue. This trend is shown by table 15, which is based on the test data given in tables 5 and 14.

S. Sabrou,[13] in reporting on a study of the aging of road tars, drew the following conclusions, based on laboratory studies. When a tar is spread on a road and subjected to the climatic conditions prevailing in France, it undergoes an aging which is not attributed to polymerization due either to heat or the ultra violet light of the sun, but which is attributed to slow and slight oxidation and above all to the evaporation of the lighter constituents. He intimated that the effect of evaporation is at least 100 times that of oxidation.

Some of the inherent changes developed on exposure can probably be traced to the high loss of volatile matter which occurred early in the exposure period, thereby causing a considerable reduction in film thickness. This reduction in film thickness undoubtedly caused the material to weather more rapidly. An example of this is shown by the test results on the four samples submitted by producer E. These data are shown in table 16.

Since these materials are probably from the same base, they may be assumed to be comparable. The figures show that as the loss of volatile material increases with attendant decrease in film thickness, the index of increase in free carbon also increases. Thus it is indicated that the more viscous tars, which lose less volatile material and produce greater film thicknesses, should weather less rapidly than the lighter tars.

Table 15.—*Comparison of free carbon content of original material and index of increase in free carbon for exposure residues*

Number of samples	Free carbon in original materials			Index of increase in free carbon for residues after 15 weeks' exposure		
	Maximum	Minimum	Average	Maximum	Minimum	Average
	Percent	*Percent*	*Percent*			
5	5.42	3.76	4.72	339	214	285
12	7.91	6.06	6.92	237	155	184
12	11.67	8.15	9.68	201	94	141
6	21.09	12.23	15.57	150	117	132

Table 16.—*Results of tests on the 15-week exposure residues of samples obtained from producer E*

Sample no.	Loss	Softening point	Index of increase in free carbon
	Percent	° *C.*	
33	30.5	71.5	339
35	25.6	64.5	240
32	19.7	68.7	237
34	10.5	66.0	189

Table 17.—*Comparison of averaged* [1] *test results on distillation and exposure residues*

Test	Average total loss	Average penetration of residue	Average softening point of residue	Average index of increase in free carbon
	Percent		° *C.*	
Distillation	25.3	46.7	49.0	114
5-week exposure	22.3	15.5	57.5	150
10-week exposure	23.2		64.9	164
15-week exposure	24.0	3.3	69.1	176

[1] Data for samples 22, 23, and 31 excluded.

A general comparison of the effects of exposure as compared to the effects produced by the distillation test may be clearly seen in table 17. This table shows that the 5-week exposure residues are considerably harder than their corresponding distillation residues.

The continued increase in hardness and the increase in free-carbon content of the residues exposed for longer periods without much additional loss of volatile matter indicate that the changes in the character of the residues after exposure are due to other causes than mere loss of volatile matter. There is evidence that both oxidation and carbonization are responsible for the changes that take place when bituminous materials are exposed to air and sunlight. The great increase in the free-carbon content of the tars subjected to exposure, as well as the greater hardness of the exposed residues, indicates quite clearly that mere evaporation is not responsible for the highly altered residues obtained.

HUBBARD-FIELD STABILITY TEST USED TO DETERMINE BONDING STRENGTH BEFORE AND AFTER EXPOSURE

This and previous investigations have shown that on exposure tars develop free carbon in excess of that caused solely by concentration. No efforts have been made to determine the character of this free carbon. G. T. Gilbert and J. G. Mitchell [14] have stated that quantitative determinations show that tars oxidize in the dark and that this oxidation is accelerated by light with the formation of material insoluble in benzene (free carbon). These writers have advanced a new conception of tars based on the solubility of tar in various solvents. They indicate that free carbon is of four types: C_1, insoluble in all solvents; C_2, insoluble in benzol (C_6H_6) but soluble in pyridine; C_3, insoluble in ethyl ether but soluble in benzene; and C_4, insoluble in light naphtha (40°–60° C. boiling point) but soluble in ether. They intimated that the formation of this benzene-insoluble free carbon can be detected by determining the C_1 and C_2 content of the original and exposed tars. The ratio $\frac{C_1+C_2}{C_1}$ then gives a measure of increase distinct from that caused by simple concentration resulting from evaporation. The character of the free carbon formed in exposed tars, based on the solubility of the original material and the residue from exposure in benzene or carbon disulphide and pyridine, may prove of value in detecting the internal alterations that accompany the weathering of tars.

Road tars when used in the road surface develop adhesiveness or binding strength in various ways depending upon the grade of tar and the type of construction in which it is used. The tars that are used in penetrative treatments such as primers, those used as binders for cover stone in surface treatments and seal coats, and those used as binders for coarse open-graded mixtures, either plant or road mixed, and in some cases for closely graded mixtures, all develop their initial binding strength through the loss of their more volatile constituents, or through stiffening of the material on cooling, or a combination of both.

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[10] The Effects of Exposure on Tar Products, by C. S. Reeve and B. A. Anderton. Journal of Franklin Institute, vol. 182, no. 10, October 1916.

[13] Congres de l'Industrie de Gez, Paris 5–10, Juin 1934.

[14] The Constituents of Tar, Highways and Bridges, vol. II, no. 53, June 19, 193[illegible]

Cold-application tars have little bonding strength when first applied to the road, but by rapid loss of volatile matter soon provide a very stable surface. Hot-application tars of both the surface treatment and construction grades possess sufficient bonding strength when cooled in the road surface to withstand immediately the stress of traffic, although the initial bonding strength of the hot-surface-treatment tars may be further increased by the loss of volatile matter. The ultimate bonding strength of all road tars is undoubtedly increased by a continued loss of volatile matter and by inherent changes when exposed to service conditions.

In order to determine the initial bonding strength and its development, a series of tests were made using the Hubbard-Field stability apparatus. This equipment has been extensively used to study the effects of various physical properties of asphaltic materials on the stability or resistance to displacement of fine-graded asphaltic mixtures.[15]

Determinations of the bonding strength or adhesiveness of the 35 tars were made by preparing Hubbard-Field stability cylinders containing 16.6 percent by volume of original materials and their residues from distillation and 83.4 percent of a standard sand. These molded specimens are designated as series 1 cylinders.

The development of bonding strength was determined by preparing cylinders using the same percentage of original materials and sand as stated above and exposing the compressed specimens to the same conditions as the thin films. For comparative purposes cylinders were prepared using the amount of each distillation residue that would have been present had the percentage of tar in the cylinders containing the original material been subjected to the distillation test. These specimens, together with the exposed cylinders are designated as series 2 cylinders.

The aggregate used in making these tar mixes was the same Potomac River sand used in the previous work on liquid asphaltic mixes.[12] The sand was washed, separated into various sizes, and recombined to give the following grading:

	Percent
Passing sieve no. 10, retained on sieve no. 20	3.7
Passing sieve no. 20, retained on sieve no. 30	10.3
Passing sieve no. 30, retained on sieve no. 40	18.1
Passing sieve no. 40, retained on sieve no. 50	21.3
Passing sieve no. 50, retained on sieve no. 80	36.6
Passing sieve no. 80, retained on sieve no. 100	6.1
Passing sieve no. 100, retained on sieve no. 200	3.2
Passing sieve no. 200	.7

The tar products and sand were thoroughly mixed by hand. Three cylinders were prepared for each test condition. All cylinders were compacted under a load of 3,000 pounds per square inch. Since the 35 tars varied greatly in consistency, the test procedure for making and testing the Hubbard-Field specimens varied as follows:

1. The original materials intended for cold application were mixed and compressed at room temperature.
2. The original materials intended for hot application were mixed and compressed at 40° C.
3. All distillation residues were mixed and compressed at 80° C.
4. In forming cylinders containing the original materials, the pressure was released as soon as the required total load was reached. For the cylinders containing the distillation residues the total load was held for 2 minutes, and the mold was flooded with cold water to chill the specimens.
5. The bonding strength or stability of the cylinders containing the original materials was determined at 25° C. only. The cylinders from the 5-week period of exposure were tested for stability at 25° C. and, if the total load was over 10,000 pounds on the first specimen, the other two specimens were tested at 60° C. The cylinders containing the distillation residues were tested at 60° C. except in a few cases where one of the three cylinders was tested at 25° C. The stabilities of the cylinders exposed for 10 and 15 weeks were all determined at 60° C.

EXPOSED CYLINDERS HAD MUCH HIGHER STABILITIES THAN CYLINDERS MADE WITH DISTILLATION RESIDUES

The results of the stability tests on cylinders of series 1 are given in table 18, and those on series 2 are given in table 19. These data have been plotted in figures 13, 14, and 15.

In figure 13 the stability of the cylinders made with the cold-application tars has been plotted against

TABLE 18.—*Results of tests on series 1 cylinders*

Type of material	Identification	Original material			Distillation residue [1]			
					Stability			
		Stability at 25° C.	Specific viscosity at 40° C.	Float at 50° C.	Tested at 60° C.	Tested at 25° C.	Softening point	Penetration at 25° C.
		Pounds		*Seconds*	*Pounds*	*Pounds*	° C.	
TC-1	7	0	9.2		800		54.0	21
	14	0	10.7		1,475		61.7	9
	20	0	9.5		850		55.4	12
	24	0	11.8		925		54.4	13
TC-2	1	15	15.9		513	8,100	50.1	30
	15	10	15.5		1,513		62.7	8
	21	25	17.3		790		57.0	8
	33	60	16.2		398		58.1	36
TC-3	16	63	21.2		1,617		63.1	7
	25	70	20.7		585	10,000+	52.2	19
TC-4	3	87	34.9		650		54.0	16
	17	90	32.5		1,833		64.4	5
TM-1	8	100	40.1		525	6,050	48.4	39
	11	80	53.5		538	6,900	49.2	41
	18	90	48.5		1,567		64.1	6
	35	117	57.4		375	9,100	48.2	36
TM-2	5	153	70.4		608		52.5	18
	19	133	70.6		2,030		65.8	5
	26	173	83.7		488	9,800	50.7	25
TR-1	9	153	44.5		1,892		65.0	7
TR-2	6	178	60.7		1,150		60.4	5
	10	153	73.1		1,260		61.0	9
	27	163	63.1		1,010		59.5	6
TH-1	2	580		58	1,110		58.1	9
	12	380		51	475	5,800	44.8	67
	32	310		43	225	4,200	39.7	98
	28	783		78	550		52.8	21
TP-1	13	1,200		107	800		54.0	22
TP-2	29	1,958		126	883		56.0	10
TP-4	4	2,842		167	1,375		60.1	5
TP-6	30	3,417		194	800		56.8	12
	34	2,258		165	625		54.4	13
Special	22	310		30	1,700		61.6	6
	23	0	2.0		892		52.7	26
	31	1,360		51	4,867		75.6	1

[1] Residue from A. S. T. M. D 402-34 T distillation test.

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[12] Curing Studies of Liquid Asphaltic Materials, by R. H. Lewis and W. O'B [illegible]. Public Roads, vol. 16, no. 6, August 1935.

[15] A Study of Some Factors Affecting the Stability of Asphalt Mixtures, by Prevost Hubbard and F. C. Field. Proceedings A. S. T. M., vol. 26, pt. II, 1926.

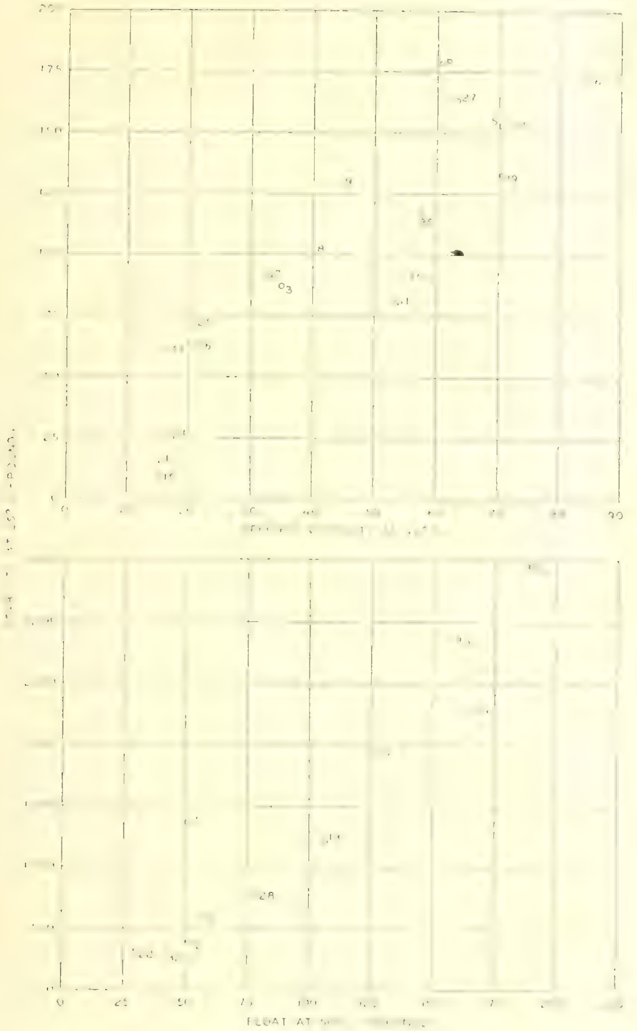

Figure 13.—Relations Between the Consistencies of Original Materials and the Stability at 25° C. of Series 1 Cylinders.

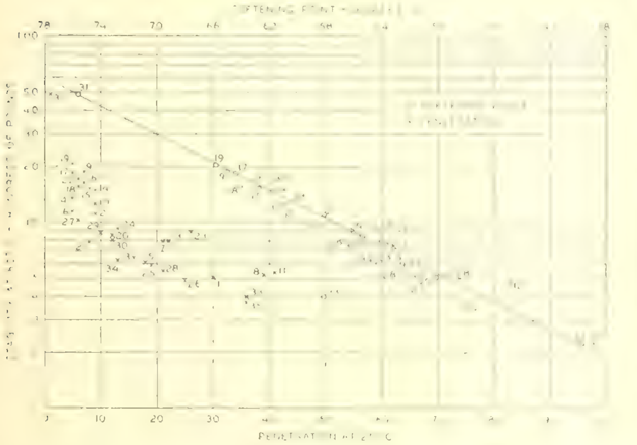

Figure 14.—Relations Between Consistencies of the Distillation Residues and Stability at 60° C. of Series 1 Cylinders.

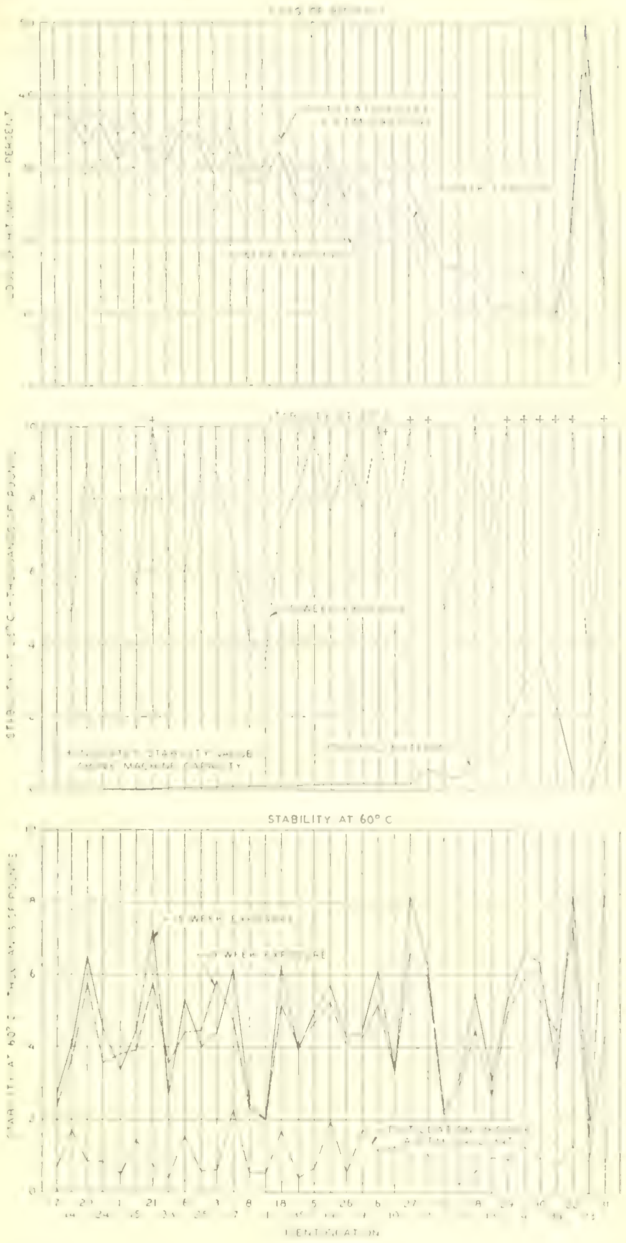

Figure 15.—Comparison of Loss of Bitumen and Stability of Series 2 Hubbard-Field Cylinders.

the Engler specific viscosity at 40° C. of the contained tar, and for the cylinders made with the hot-application tars the stability is plotted against the float test in seconds at 50° C. The stability values obtained on the cylinders containing the cold-application materials are low since the viscosity range indicates relatively fluid products. The greater consistency of the hot-application materials results in higher stability values. Generally, with both types of material the higher the consistency of the tar used as binder the higher was the stability. A comparison of the two curves clearly illustrates the difference in binding ability of cold- and hot-application materials immediately after being applied. The cold-application materials must rapidly lose much of their volatile constituents to increase the stability of the road surface.

The stability of the cylinders containing the distillation residues was plotted against the softening point and penetration of the contained tar pitch, as shown in figure 14. The softening point value showed a more constant relation than did the penetration value, indicating that the softening point value of a tar pitch is the better measure of its relative bonding strength. The relation between stability and penetration did

TABLE 19.—*Results of tests on series 2 cylinders*

Type of material	Identification	Cylinders made with the original materials								Cylinders made with distillation residue [1]		
		Stability					Loss of bitumen in—			Stability		Theoretical loss of bitumen
		As made, tested at 25° C.	5 weeks		10 weeks, tested at 60° C.	15 weeks, tested at 60° C.	5 weeks	10 weeks	15 weeks	Tested at 60° C.	Tested at 25° C.	
			Tested at 60° C.	Tested at 25° C.								
		Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	*Pounds*	*Pounds*	*Percent*
TC-1	7	0	....	5, 300	2, 400	2, 725	32	36	37	700	....	37
	14	0	....	4, 950	3, 675	4, 075	32	35	37	1, 693	....	39
	20	0	....	8, 950	5, 725	6, 475	29	33	33	858	....	36
	24	0	....	7, 000	3, 575	4, 475	31	36	36	850	....	38
TC-2	1	15	....	6, 800	3, 800	3, 375	28	32	31	500	8, 500	35
	15	10	....	5, 600	3, 925	4, 475	30	33	35	1, 478	....	38
	21	25	3, 900	10, 000+	5, 775	7, 225	26	29	31	758	....	32
	33	60	....	6, 450	3, 575	2, 725	26	32	31	425	....	34
TC-3	16	63	....	6, 000	4, 400	5, 325	29	34	35	1, 475	....	37
	25	70	....	8, 650	4, 425	4, 000	28	33	33	600	8, 800	34
TC-4	3	87	....	8, 750	5, 825	4, 400	24	28	29	633	....	32
	17	90	....	6, 850	4, 675	6, 125	27	30	32	2, 225	....	35
TM-1	8	100	....	4, 100	2, 300	2, 375	23	27	28	563	5, 550	29
	11	80	....	3, 600	2, 000	1, 975	24	28	28	525	5, 900	30
	18	90	....	7, 350	5, 150	6, 225	26	30	32	1, 683	....	35
	35	117	....	8, 300	3, 950	3, 800	21	26	26	400	7, 100	29
TM-2	5	153	2, 500	9, 750	4, 600	4, 975	21	26	25	667	....	28
	19	133	....	7, 650	5, 250	5, 725	25	30	30	1, 917	....	32
	26	173	....	9, 200	4, 075	4, 275	20	26	26	563	8, 900	26
TR-1	9	153	....	7, 750	4, 250	4, 375	22	26	26	1, 725	....	30
TR-2	6	178	4, 450	10, 000+	5, 200	6, 075	21	25	24	1, 138	....	28
	10	153	....	6, 950	3, 325	3, 350	22	25	25	1, 250	....	28
	27	163	4, 375	10, 000+	6, 575	8, 150	21	25	25	1, 098	....	27
TH-1	2	580	4, 200	10, 000+	5, 975	6, 175	15	19	19	1, 033	....	22
	12	380	....	4, 950	2, 100	2, 250	13	16	16	538	5, 800	17
	32	310	....	7, 050+	2, 900	3, 125	10	17	16	225	3, 650	16
	28	783	2, 600	10, 000+	4, 475	5, 425	11	15	15	600	....	16
TP-1	13	1, 200	....	5, 450	2, 625	3, 050	7	9	11	983	....	13
TP-2	29	1, 958	3, 750	10, 000+	4, 925	5, 325	8	11	11	917	....	15
TP-4	4	2, 842	4, 325	10, 000+	5, 900	6, 600	6	10	10	1, 267	....	16
TP-6	30	3, 417	3, 900	10, 000+	5, 225	6, 350	6	9	10	925	....	11
	34	2, 258	2, 200	10, 000+	4, 425	3, 375	5	10	9	708	....	9
Special	22	310	4, 975	10, 000+	7, 300	8, 175	17	20	20	1, 288	....	22
	23	0	....	2, 500	1, 525	2, 000	43	47	50	883	....	49
	31	1, 360	7, 200	10, 000+	8, 300	....	10	14	13	4, 317	....	20

[1] Residue from A. S. T. M. D 402–34 T distillation test.

show, however, that for equal penetrations the water-gas tar residues generally gave higher stabilities than the residues from coal tars or coal-tar blends.

The Hubbard-Field stability values for the series 2 cylinders are shown in figure 15, along with the percentages of volatile matter lost under test conditions. Although in the cylinders made with the original materials the loss of volatile matter after exposure was very close to the loss in the distillation test, the stabilities of the cylinders exposed for 15 weeks were much greater than the stabilities of the cylinders prepared with the distillation residues. This shows that changes other than loss of volatile matter have produced a condition in the mixture that results in a greater bonding strength, just as greater hardening and internal alterations in the exposed films tended to produce residues dissimilar to those developed in the laboratory distillation tests.

The loss of volatile matter for the cylinders exposed for 10 weeks is not shown in figure 15 since it closely approximated the loss at 15 weeks. But figure 15 shows that in the cylinders of many materials there were increases in stability from 10 to 15 weeks that may be attributed to additional hardening or change in the contained tar residue without corresponding loss of volatile matter.

W. E. Cone has stated [16] that: "The ease and facility with which tar wets a particular surface and retains the full value of its adhesive properties while being gradually changed to a solid is one of its most striking characteristics."

While testing exposed cylinders that initially contained liquid asphaltic material even of the rapid-curing type, it was observed that while a hardened crust formed, which in some cases was very thick, the mixture in the center of the test specimens was plastic after 15 weeks of exposure. The exposed cylinders containing these tar products, in many cases after 5 weeks of exposure and in all cases after 15 weeks, appeared to be uniformly hard and solid throughout the entire mass, indicating that ultimate hardening of the contained tar is not materially retarded by the formation of a surface crust.

Some idea of the rapid development of binding strength in the exposed tar cylinders may be obtained by comparing the stabilities obtained for the tar mixtures with the stabilities obtained on similar cylinders made with slow- and rapid-curing liquid asphaltic materials and exposed at the same time. Cylinders made with 23 slow-curing liquid asphaltic materials that had initial stabilities of from 25 to 175 pounds, had developed stabilities at the end of 15 weeks of from 300 to 3,075 pounds. Cylinders made with six medium- and rapid-curing liquid asphaltic materials had initial stabilities of from 25 to 275 pounds and developed stabilities ranging from 1,650 to 5,200 pounds at the end of 15 weeks.

At the end of 5 weeks the cylinders containing the TC, TM, and TR tars had developed stabilities ranging from 3,600 pounds to more than 10,000 pounds at the test temperature of 25° C., which was also the control temperature of the tests on the cylinders containing the asphaltic materials. For these cold-application materials, only cylinders containing tars 8, 11, and 14 had lower stabilities after 5 weeks of exposure than the maximum value obtained on the asphaltic materials for 15 weeks of exposure. At the end of 15 weeks, the cylinders containing the cold grades of tar had developed stabilities ranging from a minimum of 1,975 to a maximum of 8,150 pounds at 60° C., the minimum stability being many times greater than the maximum developed with the asphaltic materials. These data seem to substantiate the fact that tar products in service harden more rapidly and ultimately produce harder and less plastic road mixtures than do asphaltic materials.

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[16] The Qualities of Tars for Use in Roads and Streets. Canadian Engineer, vol. 67, no. 4, July 24, 1934.

CONCLUSIONS

The data obtained on these tar products when submitted to laboratory tests and when subjected to exposure conditions justify the following conclusions.

1. The road tars submitted by the five producers were, with few exceptions, well within the limits of the various grades of materials meeting the Federal specifications.

2. The Saybolt-Furol viscosimeter is well adapted to the determination of the consistency of fluid tars.

3. The vapor end point of 300° C. (572° F.) as required by distillation method A. S. T. M. D 20–30 is approximately equivalent to a liquid end point of 360° C. (680° F.) as required by distillation method A. S. T. M. D 402–34 T. However, the control of intermediate cutting points by the temperature of the liquid residue may result in fractions with widely different boiling points so that the character of the distillates from various materials cannot be accurately determined.

4. The greatest difference in results obtained by the two distillation methods is caused by the different methods of pouring the residues. A. S. T. M. method D 402–34 T results in residues that have undergone a greater loss of volatile matter and are correspondingly harder as measured by the softening point and penetration tests.

5. The residues from distillation generally have good ductility at 25° C., but this ductility is rapidly lost when the temperature of test is reduced.

6. When thin films of these tars were subjected to the exposure conditions of this investigation it was indicated that:

(*a*) The ultimate loss on exposure approximates the total loss of volatile matter in the A. S. T. M. D 20–30 distillation test.

(*b*) The greater hardness of the residues from exposure as compared with the hardness of the distillation residues results from causes other than the mere loss of volatile matter.

(*c*) The increased hardness of the exposure residues was accompanied by an increase in free carbon content much greater than the amount that was caused by concentration, this being attributed to oxidation, carbonization, or both.

(*d*) The test data indicate that in general the index of increase of free carbon in the residues from exposure is higher for those tars having initially low free carbon contents.

7. While the initial stability or binding value of the sand mixtures containing the more fluid tars is relatively low, it is roughly proportional to the consistency of the tar used.

8. The bonding strengths of the distillation residues are more nearly proportional to their softening point values than to their penetrations.

9. The development of stability or bonding strength in the tar and sand mixtures proceeded rapidly under the exposure conditions of this investigation, producing stability values much higher than could be obtained by mere loss of volatile matter and developing specimens which, when broken, gave no evidence of retaining plastic properties.

10. The amount of volatile matter and the consistency of the residues from the laboratory distillation test, together with the behavior of these materials in thin films and in molded specimens, indicate that road tars are rapid-hardening types of bituminous materials.

PRESERVE BENCH MARKS FOR FUTURE USE

By HOWARD S. RAPPLEYE, Chief, Section of Leveling, United States Coast and Geodetic Survey

IN THE extension of its system of control surveys over the United States, the Coast and Geodetic Survey has run many hundreds of lines of levels, of first- or second-order accuracy, which now form a great net over the entire country with the lines spaced, except in some of the more inaccessible regions in the West, at intervals of about 25 miles. Bench marks are spaced along these lines at intervals of from 1 mile or less to a maximum distance of 3 to 5 miles.

These bench marks and their published descriptions and elevations represent a vast outlay for field work, computation, and adjustment. In order that the results of this work may be useful to all engineers throughout the Nation the marks must remain in place undisturbed or be relocated in such a manner as to preserve their usefulness.

In spite of the extreme care exercised by the field parties, in placing bench marks where they are likely to remain undisturbed for a long time, it sometimes becomes necessary to destroy them to make way for construction, repair, or maintenance work of various kinds. A bench mark once disturbed, without transfering its elevations to some other mark which is set to preserve it, is a total loss and leaves a gap in the line of levels which requires extra running for all engineers who may be called on to do leveling in the locality at any future time.

It is to the interests of all concerned to relocate bench marks which are in the way of construction rather than to allow them to be completely destroyed. The Coast and Geodetic Survey does not have funds available for placing parties in the field to go about and relocate bench marks which must be moved to avoid their destruction. On the other hand, since the marks are chiefly useful to practicing engineers, whether public or private, we look to all engineers throughout the country for cooperation in preserving these useful marks in their own interests as well as in the interests of their government.

A routine method of handling cases of this sort has been worked out and if followed out, as outlined below, the loss of bench marks and its accompanying inconvenience and loss to the engineers and surveyors of this country will, to a large extent, be avoided.

As soon as it becomes known that a mark must be moved, a letter should be sent to the Director, United States Coast and Geodetic Survey, Washington, D. C., attention Section of Leveling, stating the necessity for moving the mark and giving its designation. The designation consists of the letters and numbers found to have been stamped with dies on the disk. It is desirable to furnish a rubbing of the disk as well. A rubbing can be made by placing a piece of medium-weight paper over the disk and then rubbing over the paper with a hard pencil to bring out the legend cast in the disk, especially the letters and numbers stamped on it with dies.

Upon receipt of this information, this office will send out a new disk properly stamped to show that it has been reset. Necessary instructions for the establishment of the new mark and the transfer of elevation will also be sent. The proper procedure, in most cases, is to establish the new mark in a safe place nearby and transfer the elevation from the old mark to the new one by means of an engineer's level and rod. The levels should be run in duplicate to avoid the possibility of large errors, and all readings should be made to three decimal places in order to preserve the accuracy of the original elevation.

The old mark should not be disturbed until the observations involved in the transfer have been checked by the observer or the recorder. An assumed elevation for the old mark may be used in the transfer, since what we are primarily concerned with in a case of this sort is the difference in elevation between the old mark and the new one established to replace it.

After the new mark has been established and the elevation transferred to it, the old disk should be broken out and returned to this office in a franked mailing sack which will be supplied for the purpose. A complete report on the action taken, including a description of the location in which the new mark is established and a copy of the field notes involved in the transfer of elevation, should also be forwarded to this office; a franked envelope will be furnished for this purpose.

The cooperation which individuals and organizations may extend to this office in preserving the benchmarks will be a service not only to this bureau and other government surveying organizations but to anyone who may have occasion to use the marks.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS
1936 AND 1937 FUNDS

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287				$ 78,130	$ 39,065					$ 5,169,222
Arizona	3,564,709	$ 1,051,145	$ 784,504	70.0	982,902	832,267	31.5	$ 4,812	$ 3,327		1,944,610
Arkansas	4,275,929										4,275,929
California	9,508,671	565,511	326,945	9.5	6,435,811	3,689,093	146.7	1,480,136	814,330	33.3	4,678,303
Colorado	4,575,144	1,567,253	877,141	69.4	1,554,737	866,533	43.1	302,945	169,908	7.0	2,661,562
Connecticut	1,582,913				857,841	426,718	9.2	230,938	115,469	5.7	1,040,726
Delaware	1,218,750				439,749	219,874	34.4	59,102	29,551	.1	969,325
Florida	3,315,558	518,283	259,142	17.9	574,442	287,221	13.4				2,769,195
Georgia	6,336,443	157,625	78,812	10.7	1,298,920	618,936	91.1	1,457,654	728,827	73.9	4,909,868
Idaho	3,065,304	470,022	270,544	75.3	1,431,250	884,287	103.0	413,569	240,480	24.9	1,669,994
Illinois	10,325,922	695,063	347,531	17.3	6,746,796	3,371,042	104.3	2,501,483	1,213,741	41.5	5,393,607
Indiana	6,184,258	1,618,666	808,060	54.2	4,098,795	2,049,365	143.4	355,931	177,892	7.9	3,148,940
Iowa	6,466,628	389,534	187,819	112.8	5,934,426	2,816,470	260.2	466,381	220,010	80.2	3,242,329
Kansas	6,631,085	368,261	184,096	207.7	3,390,933	1,695,466	[illegible]	3,578,707	1,532,499	434.8	3,219,024
Kentucky	4,511,955	1,104,625	549,480	74.1	1,105,767	537,889	[illegible]	1,396,340	663,889	36.2	2,760,697
Louisiana	3,557,930	616,385	308,193	23.4	1,553,970	776,985	[illegible]	1,018,497	509,249	31.6	1,963,504
Maine	2,177,197	381,923	190,654	10.7	1,519,948	759,974	47.0				1,226,569
Maryland	2,050,870							181,230	90,615	3.3	1,960,255
Massachusetts	3,485,364				333,935	166,968	3.1	273,447	136,723	1.9	3,181,673
Michigan	7,668,768	1,458,485	727,746	52.0	5,202,068	2,598,309	198.6	6,853,189	3,426,595	207.0	916,119
Minnesota	6,849,307	1,122,548	515,029	115.2	5,526,783	2,529,117	340.6	467,650	231,875	17.4	3,573,286
Mississippi	4,387,636										4,387,636
Missouri	7,601,200	1,374,961	686,250	242.1	3,757,847	1,878,923	146.0	2,286,155	1,142,972	72.3	3,893,055
Montana	5,122,333	957,816	536,149	169.3	2,955,676	1,654,883	205.1	693,945	354,318	54.7	2,576,984
Nebraska	5,167,930	1,090,522	545,181	71.7	1,218,229	628,477	140.9	871,472	435,736	116.8	3,558,536
Nevada	3,189,479	681,448	588,620	113.5	866,531	750,155	86.7	264,361	228,857	69.0	1,621,847
New Hampshire	1,218,750	157,857	77,485	3.8	590,517	290,355	18.4	141,629	70,736	1.9	780,174
New Jersey	3,352,469	87,925	43,962	1.0	2,030,222	1,015,111	28.9	1,321,388	574,164	10.4	1,719,232
New Mexico	3,990,023	701,386	426,511	74.1	2,233,377	1,380,410	121.3	247,411	150,475	7.5	2,032,626
New York	12,306,710	55,200	27,600	.1	11,442,550	5,663,272	198.2	835,519	409,520	14.7	6,206,317
North Carolina	5,879,466	537,045	268,430	84.5	2,294,213	1,144,733	293.1	1,428,620	699,196	131.7	3,767,106
North Dakota	3,918,269				186,166	101,206	.1				3,817,063
Ohio	9,131,204				5,587,349	2,680,876	72.9	1,912,415	828,319	20.7	5,622,009
Oklahoma	5,884,927	848,455	445,863	31.5	1,480,709	775,858	41.1	1,261,362	661,092	47.7	4,002,115
Oregon	4,089,711	520,308	315,246	20.2	2,814,750	1,635,489	85.7	122,949	66,767	4.4	2,072,209
Pennsylvania	10,695,448	231,817	115,640	4.2	7,055,945	3,527,973	102.6	1,849,557	921,988	29.7	6,129,848
Rhode Island	1,218,750										1,218,750
South Carolina	3,381,337				50,787	25,393		247,279	111,276	20.1	3,244,668
South Dakota	4,078,647				1,173,391	672,472	136.2	267,769	146,818	44.4	3,259,357
Tennessee	5,268,270	555,020	276,938	24.5	1,141,552	570,776	41.6	476,618	238,309	20.8	4,182,247
Texas	15,548,821	4,977,366	2,484,703	266.2	7,432,956	3,710,933	417.9	2,242,186	1,101,887	95.3	8,251,298
Utah	2,826,960	396,384	278,469	23.3	1,402,465	1,009,301	96.1	90,496	61,317	8.7	1,477,873
Vermont	1,218,750	107,721	53,194	8.3	1,089,340	544,670	51.0	12,262	6,094		614,792
Virginia	4,559,200	116,618	58,309	4.2	2,153,428	1,074,360	85.6	628,175	314,087	19.8	3,112,444
Washington	3,904,738	861,209	452,792	25.0	2,320,438	1,220,949	88.9	6,280	3,300		2,227,697
West Virginia	2,716,754	87,161	43,581	3.0	863,374	431,675	41.6	632,462	315,731	11.5	1,925,768
Wisconsin	6,090,504	616,271	308,135	20.6	3,147,514	1,552,485	110.8	2,888,784	1,345,219	[illegible]	2,884,665
Wyoming	3,121,972	1,590,876	979,363	178.0	935,091	555,380	96.6				1,587,229
District of Columbia											
Hawaii	1,218,750				298,606	146,767	4.3	168,350	83,746	3.9	988,237
TOTALS	243,750,000	28,638,695	15,428,117	2,289.3	115,690,226	59,808,461	4,676.2	41,939,465	20,576,903	[illegible]	147,936,519

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Work Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,386,254	$ 3,386,254	105.2	$ 374,953	$ 374,953	13.0	$ 389,909
Arizona	2,569,841	$ 970,451	$ 927,032	64.5	1,956,748	1,397,356	125.2	232,846	127,105	11.0	118,348
Arkansas	3,352,061	657,603	656,894	41.8	1,934,222	1,916,902	211.4	723,246	721,083	102.8	57,183
California	7,747,928	653,155	610,958	60.6	5,413,193	5,258,862	160.2	1,732,902	1,704,711	33.2	173,397
Colorado	3,395,263	675,363	674,972	54.9	1,152,787	1,152,787	31.6	195,775	195,775	10.6	1,371,730
Connecticut	1,418,709	4,268	3,995		285,188	263,674		198,505	185,394	2.2	965,646
Delaware	900,310				460,139	460,139	45.3	79,046	79,046	13.6	361,125
Florida	2,597,144	63,820	63,820	5.5	2,029,423	2,011,551	72.5	241,062	241,062	5.9	280,711
Georgia	4,988,967	49,637	49,637	.7	561,240	561,240	42.7	305,997	305,997	14.3	4,072,093
Idaho	2,222,747	84,630	83,910	8.4	1,896,034	1,789,472	153.9	162,375	120,000	11.4	229,365
Illinois	8,694,009	610,970	610,970	44.9	6,758,462	6,758,462	355.0	1,321,010	1,321,010	72.3	3,567
Indiana	4,941,255	133,889	133,889	2.9	4,473,052	4,473,052	214.3	513,234	312,121	16.0	22,193
Iowa	4,991,664	172,442	162,450	64.3	3,031,242	2,888,616	263.9	1,149,415	1,108,475	87.7	832,123
Kansas	4,994,975	284,119	284,119	60.9	4,268,678	4,268,678	293.1	441,745	431,935	20.6	10,244
Kentucky	3,726,271	237,380	237,380	48.9	1,949,714	1,949,714	226.8	720,967	720,967	51.4	818,210
Louisiana	2,890,429				1,029,228	872,117	61.1	2,010,202	1,760,510	113.4	237,802
Maine	1,076,799	119,750	119,750	6.5	1,091,691	1,091,143	46.5	395,784	395,784	17.3	70,122
Maryland	1,750,738				306,885	306,885	11.3	1,061,650	908,825	26.7	535,028
Massachusetts	3,262,885				117,754	117,754	1.1	1,018,779	1,018,779	4.0	2,126,352
Michigan	6,301,414	477,500	477,500	25.6	5,621,171	5,561,141	252.6	128,800	128,800	9.3	133,973
Minnesota	5,277,145	664,022	576,080	154.3	3,801,549	3,410,255	488.0	1,169,181	762,895	222.5	527,915
Mississippi	3,457,552	108,921	108,921	5.3	2,846,675	2,843,252	190.6	161,912	161,912	11.8	343,466
Missouri	6,012,652	1,063,760	1,063,459	348.7	3,343,165	3,343,165	377.8	1,486,260	1,483,253	63.7	122,776
Montana	3,676,416	563,103	563,103	34.3	3,012,254	3,012,254	150.2	46,981	46,981	1.0	54,078
Nebraska	3,870,739	49,519	44,866	4.7	2,582,237	2,545,966	277.8	735,859	735,859	80.4	544,048
Nevada	2,243,074	962,035	945,035	32.6	839,408	816,839	55.9	168,524	168,524	9.4	312,676
New Hampshire	945,225	16,529	15,547	1.3	382,700	369,687	13.4	127,156	119,934	10.2	440,057
New Jersey	3,129,805				2,103,777	2,103,777	13.7	99,211	99,211	5.3	926,817
New Mexico	2,871,397	724,350	724,350	74.4	1,339,706	1,339,706	74.2	230,294	230,294	23.1	577,047
New York	11,046,377	403,833	403,833	4.1	9,776,465	9,364,664	144.4	358,160	358,160	11.9	919,719
North Carolina	4,720,173	209,500	209,500	21.6	3,103,021	3,070,432	208.1	476,192	460,019	23.2	980,222
North Dakota	2,867,245	246,308	246,308	32.0	782,701	780,331	97.4	1,400,192	1,400,192	155.3	440,414
Ohio	7,670,815	181,530	181,530	2.4	3,812,283	3,804,554	41.6	1,517,555	1,434,151	152.3	2,250,579
Oklahoma	4,580,670	149,074	149,074	16.3	2,165,898	2,163,484	176.9	1,355,611	1,355,382	175.6	912,729
Oregon	3,038,642	17,113	17,113		2,612,478	2,522,111	113.7	680,338	399,337	53.1	100,080
Pennsylvania	9,347,797	146,301	120,538	3.7	1,798,204	1,762,308	65.5	879,872	875,834	57.4	6,589,117
Rhode Island	989,208	15,934	15,934		962,220	962,220	18.9	9,192	9,192	.2	1,863
South Carolina	2,702,012	70,779	69,576	8.6	1,614,564	1,578,063	147.9	528,395	527,657	57.3	526,716
South Dakota	2,976,454	381,805	381,805	131.9	1,497,787	1,497,757	231.4	476,432	476,432	59.5	620,459
Tennessee	4,192,460	230,293	230,293	3.4	2,104,321	2,104,321	91.4	781,033	781,033	31.3	1,076,813
Texas	11,989,350	1,770,922	1,599,770	204.7	10,057,284	9,197,487	839.0	1,105,507	1,027,619	63.0	164,474
Utah	2,067,154	430,274	430,108	22.4	983,668	936,732	95.9	382,812	287,175	36.9	413,139
Vermont	924,306	145,039	136,731	3.6	747,102	640,126	15.9	126,396	112,062	2.3	35,387
Virginia	3,652,667	572,532	558,617	272.9	1,959,359	1,929,586	650.1	765,329	749,682	93.0	414,782
Washington	3,026,161	454,903	442,622	33.4	2,287,994	2,031,275	108.0	447,281	387,871	14.1	164,393
West Virginia	2,231,412				1,278,020	1,274,524	49.0	513,683	513,641	25.8	443,247
Wisconsin	4,823,884	278,186	257,269	16.1	4,173,577	3,775,249	272.8	846,859	665,678	41.3	125,688
Wyoming	2,219,155	56,249	56,247	20.0	1,856,072	1,856,054	107.7	69,397	69,396	1.5	237,458
District of Columbia	949,496	600,609	600,609	5.1	377,395	318,389	3.4				30,498
Hawaii	926,033				643,277	622,181	8.9				303,852
TOTALS	195,000,000	15,708,400	15,246,114	1,948.2	122,568,266	118,462,548	7,803.2	29,953,907	27,881,708	2,119.1	33,409,630

U. S. GOVERNMENT PRINTING OFFICE 33873

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JUNE 30, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
				NUMBER					NUMBER					NUMBER			
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1			$ 3,175,940	$ 3,175,940	32			$ 649,186	$ 649,186	7		5	$ 200,367
Arizona	1,256,099	47,412	47,412	1			994,878	925,734	10								282,953
Arkansas	3,574,060	344,478	344,210	8			1,221,787	1,217,822	23	4		1,849,214	1,846,228	22	1	3	165,801
California	7,486,362	179,113	173,867	3	2		6,427,095	6,188,037	33	5		806,253	803,410	16			321,048
Colorado	2,631,567	168,864	168,864	2			1,218,052	1,197,052	20			128,712	128,712	1			1,136,939
Connecticut	1,712,684											158,451	158,451	1	1		1,554,233
Delaware	418,239											143,486	120,000	1			298,239
Florida	2,827,883	15,489	15,489		1		1,592,776	1,590,465	15	4		490,339	490,339	11			731,590
Georgia	4,895,949						214,669	214,669	4			209,578	209,578	4	1		4,471,702
Idaho	1,674,479						1,046,976	1,027,849	18	1							646,630
Illinois	10,307,184						4,928,578	4,928,578	46	2		2,633,406	2,633,406	14	1		2,745,200
Indiana	5,111,096						3,502,651	3,380,006	28	7		1,941,453	1,702,123	10	3	127	28,967
Iowa	5,600,679	7,303	7,000		1		2,516,366	2,413,775	51	4		2,459,825	2,436,150	44	5		743,754
Kansas	5,246,258						3,971,118	3,971,118	37	1		1,275,335	1,275,140	16		3	
Kentucky	3,672,387	15,290	15,290	1			2,407,425	2,117,693	16			199,802	199,802	6	2		1,339,602
Louisiana	3,213,467						579,848	579,848	5			1,852,784	1,804,129	16	4		829,490
Maine	1,426,861						465,638	465,305	10			501,018	500,324	8			461,232
Maryland	2,061,751						414,161	414,161	3	2		967,014	944,545	3	2	11	703,045
Massachusetts	4,210,833						1,227,840	1,227,840	8	2		385,208	385,208	5			2,597,784
Michigan	6,765,197	447,400	447,400	3	1		5,057,152	5,057,152	32	7		606,350	561,850	5	1		698,795
Minnesota	5,395,441	154,269	154,269	2		1	2,645,661	2,639,611	53	6	4	729,307	729,307	13	3	26	1,872,255
Mississippi	3,241,475						1,930,102	1,930,102	41	3		207,952	207,952	4		1	1,103,421
Missouri	6,142,153						4,616,091	4,605,451	28	1		1,524,391	1,521,763	12			14,940
Montana	2,722,327	222,343	222,343	3			2,378,433	2,378,433	33	6							121,551
Nebraska	3,556,441	148,501	148,501	3			1,955,805	1,955,805	62	1		1,320,661	1,320,661	11	1	22	131,475
Nevada	887,260	185,753	185,753	4			497,919	497,919	6								203,587
New Hampshire	822,484						351,777	351,777	3	3		13,154	13,154			1	457,553
New Jersey	3,983,826						1,024,099	1,024,099	5	2		381,836	381,836	3	1		2,577,892
New Mexico	1,725,286	203,329	203,329	5			762,768	762,768	6	1		519,778	519,778	4			239,410
New York	13,577,189						8,906,354	8,645,808	29	27		1,491,550	1,491,270	2	9		3,440,111
North Carolina	4,823,958	69,554	69,554		2		1,446,849	1,446,849	20	5		685,293	685,293	9	4		2,622,262
North Dakota	3,207,473	39,335	39,335	1			761,541	761,541	18			899,072	899,072	17			1,507,525
Ohio	8,439,897						899,207	899,207	5	1		2,609,347	2,443,544	19	2		5,097,145
Oklahoma	5,004,711	219,766	219,766	5			1,382,850	1,382,850	26	1		1,900,567	1,900,567	23	2		1,501,528
Oregon	2,334,204						1,956,186	1,831,474	12	6		437,198	437,198	4		2	65,531
Pennsylvania	11,483,613	10,836	10,836	3			3,419,427	3,229,856	26	6		2,294,680	2,000,183	13	5		6,242,738
Rhode Island	699,691						654,008	654,008	4	1							45,683
South Carolina	3,059,956						1,260,469	1,249,503	22	4		211,922	211,868	8	1		1,598,586
South Dakota	3,249,086	51,774	51,774	1			854,322	854,322	23			41,601	41,601	1			2,301,389
Tennessee	3,903,979						535,673	535,673	12	1		441,019	441,019	11	1	11	2,927,287
Texas	10,855,982	235,840	226,386	7			5,179,734	4,996,144	64	11		5,566,129	5,463,758	52	4	83	169,693
Utah	1,170,763	29,757	29,757		1		609,078	537,024	9			108,047	100,000	1			503,982
Vermont	729,857	122,871	122,871	3	2		339,140	337,782	4	3		59,630	58,666	2		7	210,538
Virginia	3,774,287	103,940	103,940	6			1,259,501	1,188,637	21	2		619,167	578,007	20		9	1,903,703
Washington	3,095,041	77,705	77,705	1			1,800,209	1,795,378	15	6	1	583,785	583,785	4	1	6	638,174
West Virginia	2,677,937						276,542	276,542	2	1		491,749	491,749	3			1,909,645
Wisconsin	5,022,683	69,151	69,151	1			2,752,192	2,752,192	27	5		449,314	449,314	3	1		1,752,026
Wyoming	1,360,841	55,366	55,365	2			325,014	325,011	3								980,465
Dist. of Columbia	410,804						170,643	170,643	2			253,264	238,616	1			1,545
Hawaii	453,703						296,218	295,333	3			215,430	158,369	2			1
TOTALS	196,000,000	3,234,563	3,219,291	66	10	1	92,210,762	90,464,786	975	142	5	41,313,257	40,216,911	432	56	317	62,099,012

U. S. GOVERNMENT PRINTING OFFICE 76349

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF JUNE 30, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,437,208	$ 8,203,671	$ 2,839,626	736.4	$ 1,061,087	$ 160,296	$ 900,791	38.2		$ 462,532	2.9	$ 6,167	$ 56,893
Arizona	5,211,960	2,641,935	8,907,481	5,204,513	2,547,540	545.4	90,115		45,376	.8				7,447	49,019
Arkansas	6,748,335	3,428,049	10,738,841	6,615,313	3,152,044	608.8	224,772	21,152	203,565	10.6		50,937	1.1	111,270	21,503
California	15,607,354	7,932,206	29,241,878	15,589,248	7,458,664	758.8	1,474,347		418,015	1.6		820		18,106	54,706
Colorado	6,874,530	3,486,006	11,159,370	6,831,431	3,439,853	636.3	6,817		6,500					43,099	39,653
Connecticut	2,865,740	1,454,868	4,061,007	2,790,584	857,732	69.3	482,547		453,705	4.7				75,156	143,432
Delaware	1,819,088	923,335	2,543,857	1,819,088	732,660	128.3	88,530		88,530	.5		52,205	1.1		
Florida	5,231,834	2,661,343	8,654,439	5,183,596	2,120,961	296.7	468,781		437,733	12.2		15,955	.8	48,239	86,693
Georgia	10,091,185	5,113,491	12,093,980	9,128,958	2,471,303	683.2	1,901,442	551,957	1,282,280	108.3	$ 248,169	191,940	30.4	162,101	1,167,968
Idaho	4,486,249	2,277,486	6,624,597	4,416,568	1,792,123	496.8	429,790		425,402	4.7	42,905	2,881		26,776	57,080
Illinois	17,570,770	8,921,401	23,699,848	16,320,923	6,602,441	649.3	3,388,715	1,098,790	2,187,512	45.4	55,756	18,740	21.2	95,301	112,708
Indiana	10,037,843	5,088,963	13,783,867	9,705,689	3,442,674	429.9	1,840,290	276,180	1,497,760	58.6		134,587	.4	55,973	13,942
Iowa	10,055,660	5,118,361	15,333,142	10,055,660	4,681,121	1,215.5	197,598		181,041	3.5		196,600	5.0		59,599
Kansas	10,089,604	5,117,675	15,231,745	9,932,696	5,005,778	1,117.5	249,550	107,706	106,757	16.0	9,000	5,140	.9	40,201	
Kentucky	7,517,359	3,818,311	11,119,506	7,087,455	3,211,511	793.6	772,476	411,849	327,475	16.8	5,298	184,829	2.0	12,757	94,497
Louisiana	5,823,591	2,963,932	8,619,310	5,612,484	2,382,247	230.4	460,000	138,621	321,379	20.2	43,118	85,263	8.9	29,368	175,043
Maine	3,369,917	1,711,586	5,208,075	3,337,541	1,642,714	133.1	7,234		7,234		10,573			21,803	61,638
Maryland	3,564,527	1,810,058	4,566,259	2,899,421	688,143	119.8	1,107,732	582,686	473,331	35.6		202,667	4.6	82,420	445,916
Massachusetts	6,597,100	3,350,474	7,491,290	4,596,874	2,252,100	112.4	2,701,150	1,896,851	804,299	2.9		34,376	.2	103,376	259,699
Michigan	12,736,227	6,452,568	18,875,715	12,532,714	4,936,168	688.7	1,640,525	163,400	1,419,147	79.6		30,825	.1	40,113	66,427
Minnesota	10,656,569	5,425,551	15,504,623	9,925,146	4,723,885	1,632.7	831,555	589,493	208,244	13.1	3,168	125,320	.6	138,762	368,103
Mississippi	6,978,675	3,540,227	11,693,232	6,572,233	2,240,612	666.6	1,622,786	336,141	1,217,679	77.4	6,555	37,157	.9	63,745	44,779
Missouri	12,180,306	6,173,740	16,709,649	11,175,592	4,466,671	1,421.4	2,766,383	937,703	1,603,634	29.9		103,435	.4	67,011	
Montana	7,439,748	3,769,734	11,122,346	7,333,301	3,120,340	1,029.6	629,892	37,320	592,572	16.6	19,000	2,000	10.3	50,127	54,822
Nebraska	7,828,961	3,964,364	12,404,673	7,709,817	3,428,874	995.4	781,732	70,773	506,111	47.9		24,955	.2	48,371	4,425
Nevada	4,545,917	2,302,356	6,745,067	4,473,433	1,988,495	741.9	333,192	26,150	279,791	12.7		5,250		48,333	28,821
New Hampshire	1,909,839	969,462	2,973,832	1,904,951	937,585	77.7								4,889	31,877
New Jersey	6,346,039	3,220,879	7,678,270	6,132,040	1,050,400	81.0	1,868,176		1,669,223	6.3		303,276	6.6	213,999	197,980
New Mexico	5,792,935	2,941,700	8,668,002	5,624,746	2,818,758	762.8	50,695		33,709	2.3				168,189	89,232
New York	22,330,101	11,327,921	38,028,504	21,535,626	9,859,764	801.8	2,174,190	548,520	1,268,899	15.3	125,154	78,420	6.2	120,801	120,838
North Carolina	9,522,293	4,840,941	14,526,302	9,040,046	4,264,537	1,329.3	508,028	206,852	294,640	21.0	97,130	205,439	5.6	178,266	76,325
North Dakota	5,804,448	2,938,967	7,649,643	5,567,198	1,391,771	2,009.0	843,711	73,071	717,631	111.1	36,901	265,450	20.3	127,278	564,115
Ohio	15,484,592	7,865,012	23,344,935	15,302,317	6,304,456	757.6	1,506,317	44,450	1,378,877	36.8	51,500	58,624	1.7	86,324	123,055
Oklahoma	9,216,798	4,685,180	13,848,919	9,053,666	3,822,748	794.9	741,912	147,072	593,106	11.3		6,250	.4	16,060	263,076
Oregon	6,106,896	3,097,814	9,528,859	5,969,480	2,656,217	462.4	448,303	64,950	287,815	6.0		38,544	.4	72,466	115,238
Pennsylvania	18,891,004	9,590,788	27,432,920	17,860,232	8,283,625	993.0	1,600,137	736,539	751,286	65.8	13,076	212,794	2.1	281,157	343,083
Rhode Island	1,998,708	1,014,572	2,994,178	1,998,708	860,741	88.0	139,983		139,983	1.1					13,848
South Carolina	5,459,165	2,770,954	7,328,249	5,226,451	1,880,377	589.2	751,053	101,841	627,252	31.8	30,353	79,597	5.9	100,520	183,727
South Dakota	6,011,479	3,047,643	8,564,243	5,717,672	2,273,513	1,491.1	725,063	103,357	621,706	47.3	10,867	73,940	14.1	179,583	78,484
Tennessee	8,492,619	4,302,991	12,598,156	8,368,445	3,326,701	474.8	1,031,391	124,174	811,418	17.9		22,482	.2		142,389
Texas	24,244,024	12,291,253	36,803,831	23,842,043	11,108,867	2,753.4	1,508,008	325,282	1,087,761	32.7		500	7.1	76,698	94,126
Utah	4,194,708	2,132,691	7,149,296	4,162,416	1,973,869	586.5	202,180		156,741	4.3	32,292	1,853			228
Vermont	1,867,573	948,007	3,031,551	1,863,531	839,662	137.6	110,521	3,922	91,982	2.4		8,040	1.0	120	8,323
Virginia	7,416,757	3,765,387	11,388,302	7,216,130	3,225,650	585.1	288,187	40,037	240,322	30.3	53,539	24,235	3.0	107,051	275,181
Washington	6,115,867	3,106,412	9,238,359	6,098,252	2,910,054	302.5	121,627		115,530	.3	13,790	660		3,825	80,168
West Virginia	4,474,234	2,280,335	5,653,418	4,287,913	1,131,244	189.9	1,019,252	112,719	830,932	32.0	9,941	218,830	1.3	63,661	99,329
Wisconsin	9,724,881	4,941,837	15,009,736	9,676,693	4,537,248	610.6	341,449	7,300	291,707	9.1		72,897		40,888	39,985
Wyoming	4,501,327	2,287,712	6,847,243	4,474,802	2,163,929	1,035.9	36,744	5,780	30,962	1.4	5,949	30,155	.4	14,797	62,666
District of Columbia	1,918,469	973,842	2,747,515	1,909,584	837,795	20.8	120,199		84,699	1.5				8,885	51,348
Hawaii	1,871,062	949,778	2,520,198	1,793,257	180,263	49.4	803,632	63,609	736,463	6.1	13,517	23,433	.2	679	9,619
TOTALS	394,000,000	200,000,000	592,275,466	379,685,748	160,916,054	33,982.1	42,499,796	10,116,543	28,858,507	1,151.9	937,551	3,693,833	168.5	3,260,158	6,531,606

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 6 ▽ AUGUST 1936

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 17, No. 6 August 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DIGEST OF REPORT ON ARKANSAS TRAFFIC SURVEY

BY THE DIVISION OF HIGHWAY TRANSPORT, BUREAU OF PUBLIC ROADS

Reported by L. E. PEABODY, Senior Highway Economist

THE Arkansas traffic survey was conducted under a cooperative research agreement between the Bureau of Public Roads and the Arkansas State Highway Commission during the period from April 1934 to June 935.

The survey was undertaken to obtain essential facts egarding the amount, type, and distribution of traffic, o be used as a basis for planning highway development o serve present and future traffic. Included in the ull report,[1] which has been published by the State of Arkansas, is a detailed study of the origin and destination of vehicles; a brief summary of facts regarding the movement of passenger cars and busses; an extended analysis of truck and bus transportation at several ocations throughout the State; and a discussion of ourist traffic in Arkansas, including the purposes of visiting Arkansas, the type of accommodations used, the number of persons carried, and the average length of visit.

Owing to the relative traffic importance of the several systems of highways, the following brief description of their character and functions is given:

State highway system.—Those roads legally designated as under the complete jurisdiction of the State highway commission.

Federal-aid system.—Trunk-line highways and highways connecting county seats upon which the expenditure of Federal-aid funds is concentrated, comprising about 7 percent of the total road mileage.[2]

U. S. system.—Numbered and marked highways orming an interconnected system of through routes and distinguished by the United States shield marking. These highways have no special legal status and receive no special funds by reason of being designated U. S. highways.

Forest highway system.—Highways under the jurisdiction of the Forest Service (within or appurtenant to the national forests).

The traffic survey covered over 8,000 miles of road, all of which were on the State highway system. This coverage, amounting to 91 percent of the State highway system, included most U. S. highways and a large portion of Federal-aid and Forest highways as shown n table 1.

TABLE 1.—*Mileage of roads included in the various highway systems, and mileage of each system included in the traffic survey*

Highway system	Total mileage [1]	Miles included in traffic survey	Percentage of total system studied
State	8, 822	8, 043	91
Federal aid	5, 157	5, 063	98
U. S.	2, 740	2, 678	98
Forest	427	320	75

[1] Exclusive of streets in cities of 2,500 or more inhabitants.

AVERAGE TRAFFIC OVER ALL HIGHWAYS STUDIED WAS 369 VEHICLES PER DAY

Actual field operations of counting and classifying traffic began on April 23, 1934, and terminated June 1, 1935. In the analysis of the field records a 24-hour day and a 1-year period were the base units to which all data were adjusted.

Data were collected at 266 locations covering the principal State highways. Most of these were at intersecting highways where the field man could record traffic upon three or more roads from one location. The three types of stations operated and their number were:

	Number
Key stations	128
Blanket stations	117
Special stations	21
Total	266

Key stations, frequently referred to as "regular count stations", were situated at the most strategic control points and were operated uniformly at regular intervals during the period of the survey. Each operation covered a 10-hour period on a staggered schedule from 6 a. m. to 4 p. m. and from 10 a. m. to 8 p. m. with splits in the count at 10 a. m. and 4 p. m. This permitted a continuation series of the 10 a. m. to 4 p. m. section through all operations, which were scheduled to provide two counts for each of the seven days of the week during periods of operation. Sufficient night counts from 10 p. m. to 6 a. m. were obtained to adjust all data to a 24-hour day.

Blanket stations were situated on the less important roads and were operated four times during the survey. Data from them have been adjusted to a 24-hour day by correlation with the key stations.

Where the extent of traffic coverage was in doubt or in order to extend the coverage beyond a known point, special stations were set up and operated simultaneously with the nearest controlling key station for a number of days.

The average traffic over all roads surveyed was 369 vehicles per day and traffic ranged from 5,425 vehicles per day on U S 70 between West Memphis, Arkansas and Memphis, Tenn., to zero traffic on several unimproved sections of road in the northeast section of the State. There were three of these sections having no traffic: West of Rector on Ark. 90; south of Tupelo on Ark. 17; and south of Amagon on Ark. 37, where the road was impassable to motor-vehicle traffic during all operations of the traffic stations covering the route.

Figure 1 shows the density of traffic of all vehicles over all highways surveyed. The inner stippled band indicates the 24-hour average daily traffic density and the outer band the maximum traffic.

All recorded data were adjusted, where necessary, from supplemental information to develop daily average traffic densities over a 1-year period representative of normal conditions. Special notations were made of

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[1] The Bureau of Public Roads does not have copies of the full report for general distribution.

[2] Recent emergency legislation has permitted the expenditure of special Federal oad funds under certain conditions on roads other than the Federal-aid system.

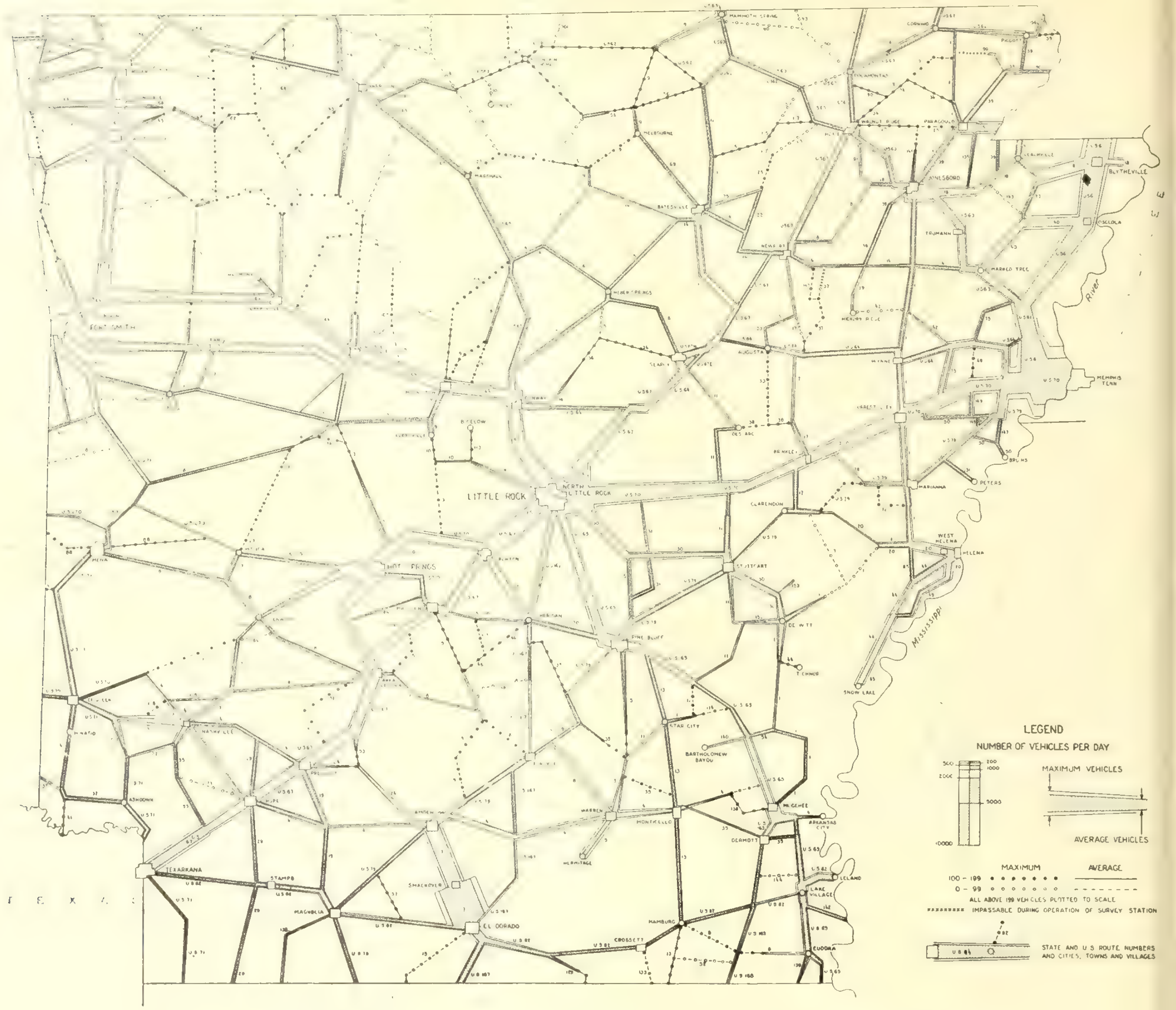

Figure 1.—Average and Maximum Daily Traffic Density on Arkansas State Highways.

trucks and other contractor's equipment engaged on highway construction and abnormally affecting traffic, and proper correction was made for them. Trucks engaged in regular highway maintenance work were considered as normal traffic and included with other trucks. A number of special movements were recorded such as the hauling of lumber, oil, cotton, and peaches and other fruits, all of which occupy a regular place in commercial activities and are a part of normal annual traffic.

Between El Dorado and Camden, there was considerable local traffic created by a large paper mill situated south of Camden and by numerous oil wells in the vicinity of Smackover and El Dorado. Between El Dorado and Smackover, most of the travel was in the nature of shuttle traffic in a restricted but highly important oil-producing area. El Dorado also has a number of important lumber mills.

In the vicinity of Fayetteville, all traffic-flow bands increase in width toward the city. The city of Fayetteville is the State's largest and most important trading center north of Fort Smith, has considerable local development in its environs, and is the home of th State University. To the north of Fayetteville, a Springdale, are located an important winery and canning factory, while farther north there is considerabl resort traffic in the region of the Ozark Mountains. Al of these factors influence traffic in this section of th State, especially on U S 71.

Particular mention is given routes Ark. 44, 49, an 85 from Helena to Snow Lake and especially in th vicinity of Elaine. Construction work on dikes an levees along the Mississippi River in this area cause abnormal traffic throughout the entire period of th survey. Consequently, for this section of the highwa system the traffic was unusually high, and because c the continuing nature of the work no weighting of th data was made.

MAXIMUM TRAFFIC WAS 143 PERCENT OF AVERAGE TRAFFIC

As may be noted by reference to figure 1 there are number of stub traffic bands some of which en abruptly for no apparent reason, and several unusu ones are explained as follows:

Traffic on Ark. 116 south of Booneville was principally destined to, or returning from, the State Tubercular Sanitorium located 2 miles south of the city. The continuation of Ark. 116 to its junction with U S 71 was unimproved and practically impassable.

Included in the surveyed mileage was 6.6 miles of Ark. 153 north of De Witt, serving a rice-growing district. Traffic over this highway was entirely farm to market. The town of De Witt is the trading and marketing center for a rich rural area and all traffic flow bands in the vicinity increase in width toward the city.

Traffic density on Ark. 15 obtained by the survey station at Warren was extended south to Hermitage. It is likely that traffic diminishes somewhat near Hermitage, but the amount could not be obtained from survey data. The section of Ark. 15 south of Hermitage was not studied.

The portion of Ark. 1 between St. Charles and Indian Bay, a distance of 6 miles, was impassable during a considerable period of the year. Improvement of this section would allow traffic from the area around the confluence of the White and Arkansas Rivers to reach Helena, where water terminal facilities exist.

Trucks were classified at all counting stations by type of equipment as single- or dual-unit loading. The single-unit group includes trucks, tractor trucks, and similar vehicles in which the load carried is one unit, whether supported entirely by the truck or with the aid of accessory wheels. The proportions of single- and dual-unit trucks were as follows:

	Percent
Trucks, including tractor trucks	85. 5
Trucks with trailers or semitrailers (2 or more units)	14. 5
All trucks	100. 0

Single-unit trucks were recorded according to rated capacity and tabulated in three capacity groups—Under 2 tons, from 2 to 5 tons, and 5 tons and over. More than 91 percent of these trucks were under 2 tons capacity, while but 0.1 percent were of 5 tons capacity or over, as shown by the following:

	Percent
Under 2 tons	91. 3
From 2 to 5 tons	8. 6
5 tons and over	. 1
All single-unit trucks	100. 0

Vehicles of foreign registration accounted for 18.7 percent of the traffic recorded at all stations, while the importance of interstate travel is illustrated by the fact that foreign vehicles at 42 border stations amounted to 40.6 percent of the total traffic.

The maximum traffic is the average peak load occurring a number of times during the year. It should not be confused with the absolute maximum traffic peak occurring but once a year. In general, the figures used refer to average maximum traffic conditions occurring on week-end periods during the summer.

For all highways studied, the maximum traffic was 143 percent of the average traffic. For 17 sections of highways, the maximum traffic was over 200 percent of the average traffic. An important characteristic of maximum traffic is its relation to the average daily traffic density; as the traffic density increases, the maximum traffic becomes a smaller percentage of the average traffic. This is illustrated in the following tabulation:

Average daily traffic (all vehicles)	Percentage that maximum traffic is of average traffic	Average daily traffic (all vehicles)	Percentage that maximum traffic is of average traffic
0– 99	180	1,000–1,499	139
100–249	153	1,500–2,499	131
250–499	149	2,500 and over	130
500–999	144		

The utility and earning value of a highway are measured in units of travel—vehicle-miles. This term is defined as the movement of one motor vehicle a distance of 1 mile, and the total travel is the product of the average traffic over a particular section and the mileage of the section.

For the State as a whole there were 2,970,000 vehicle-miles of travel daily, and the average traffic over all roads was 369 vehicles per day. Highways in Mississippi County had the most travel, and included 127 miles of highway with an average traffic of 1,184 vehicles per day. All mileages are from the official map of the State Highway Commission as of January 15, 1935, which shows all State highway mileage by type of surface exclusive of streets in cities of 2,500 or more inhabitants. Traffic count data likewise excluded traffic in cities of 2,500 or more inhabitants.

One-third of the total of 75 counties had nearly 60 percent of the total travel, as may be seen in the following distribution of counties based on vehicle-mile determinations:

	Percentage of total travel
Highest 3 counties	14. 1
Highest 10 counties	32. 9
Highest 25 counties	58. 9
Lowest 10 counties	4. 1

HIGH-TYPE ROADS CARRIED GREATEST TRAFFIC

The traffic data were further segregated and grouped by types of road surfacing and are summarized in table 2.

TABLE 2.—*Mileage of State highways studied, classified by type of road surfacing and average daily traffic*

Type	Mileage of each type	Average daily traffic
Concrete	1, 023	1, 001
Asphalt	559	780
Retread	410	439
Gravel	5, 167	241
Graded	561	109
Unimproved	323	78
Total	8, 043	369

All of the mileage studied in 15 counties had gravel or lower type of surface. Average traffic in these counties ranged from 84 vehicles per day in Marion County to 347 vehicles per day in Sevier County. In Sevier County the traffic was generally uniform, with the highest section averaging 523 vehicles per day on U S 71 between De Queen and Lockesburg. Compared to the averages for the entire State, this section had traffic equivalent to that for either the retread or asphalt group. Saline County had 8.3 miles of gravel roads carrying an average traffic of 751 vehicles per day, and Mississippi County had 28.1 miles with an average traffic of 520 vehicles per day. These figures are comparable with the State average traffic for retread and asphalt surfacing.

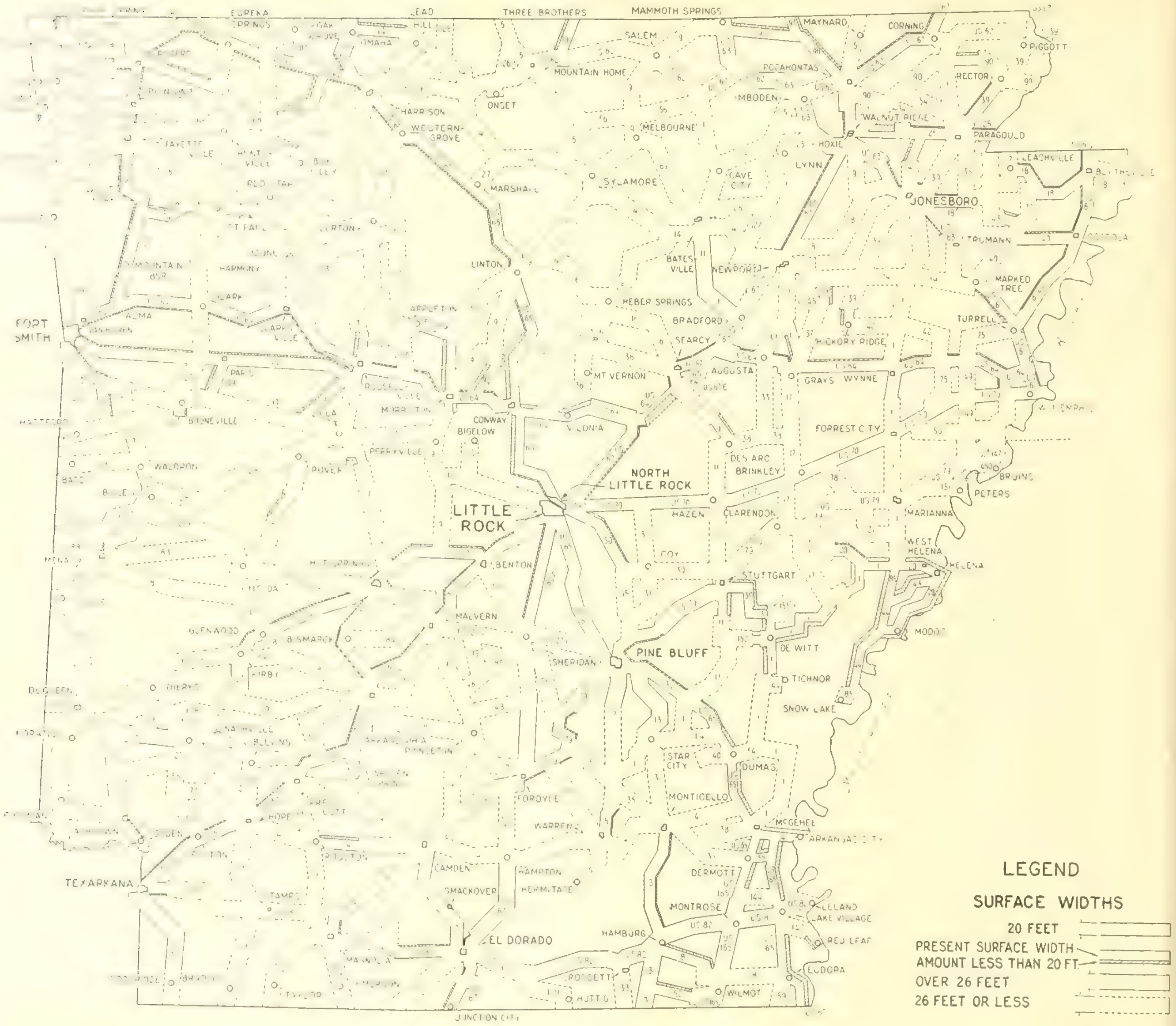

Figure 2.—Surface Widths of Arkansas State Highways Covered by the Traffic Survey.

Crittenden County showed the highest average traffic for roads with concrete surfaces—2,538 vehicles per day. Woodruff County had the lowest average traffic, or 245 vehicles per day, on its 4.1 miles of concrete road. Columbia, Lawrence, and Lincoln Counties were next in order with average traffic of 327, 356, and 397 vehicles per day, respectively, over an aggregate length of 41.9 miles.

Mississippi County had the highest average traffic for asphalt surfaced highways—1,749 vehicles over 61.6 miles of asphalt surfaced road. Perry County was low with an average traffic of 132 vehicles per day, and Conway County was next with 218 vehicles per day.

Asphalt and concrete surfaced highways of suitable width and thickness are high-type roads, capable of meeting present-day traffic requirements. In Arkansas, these two types were found upon 1,582 miles of surveyed roads, or 20 percent of the total. Average traffic for this mileage amounted to 923 vehicles per day.

Retread surfaces are an intermediate or betterment stage of construction, while gravel roads are usually classified as low type, although their condition and riding qualities may be as good or better than some higher type surfaces.

The traffic survey covered 410 miles of retread surfacing over which traffic ranged from a high of 856 vehicles per day in Pope County to a low of 207 vehicles per day in Pike County. There were no counties that showed traffic on their retread mileage comparable with the average traffic over high-type roads of approximately 920 vehicles per day. But one county, Pope, had traffic on its retread mileage exceeding the State average of 780 vehicles per day for asphalt.

Similarly, comparing the gravel surfacing group with the retread surfacing group, Mississippi and Saline Counties showed traffic on their 36.4 miles of gravel roads in excess of the State average for retread.

A total of 884 miles of graded and unimproved roads was covered by the survey, comprising 11 percent of the total surveyed mileage. Average traffic over these

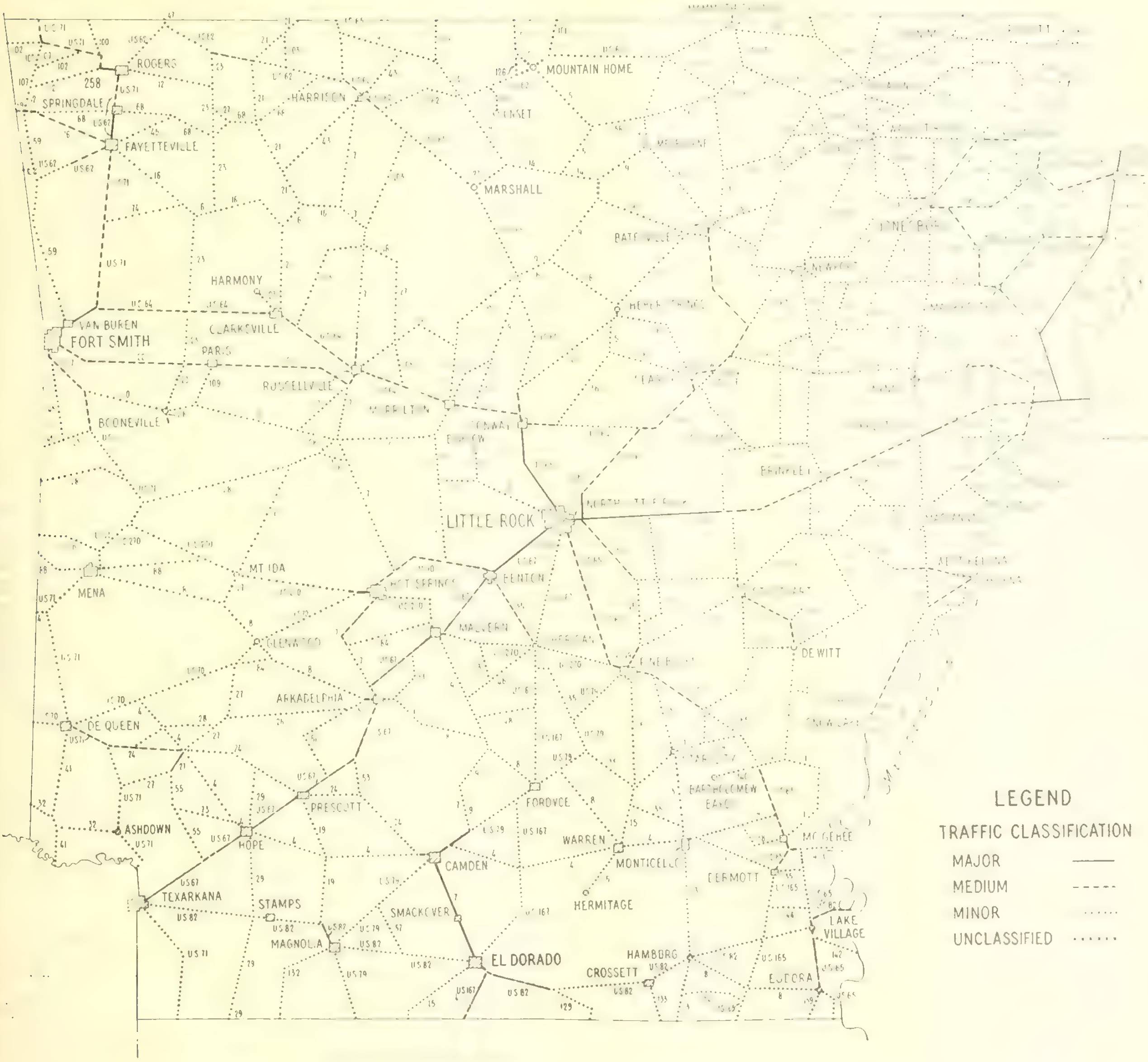

Figure 3.—Classification of State Highways by Volume of Traffic Carried.

roads amounted to 97 vehicles per day. Graded roads are distinguished from unimproved roads principally by drainage conditions, for the surfaces of each are composed of natural or filled earth and consequently are usually dusty in dry weather and slippery in wet weather. Gravel surfacing is the next higher stage of construction, when required by traffic or to make the road an all-weather highway. Three counties showed average traffic on their graded and unimproved roads greater than the average for gravel in the State as a whole. These counties were: Benton, with 10.8 miles of graded road carrying 387 vehicles per day: Garland, with 24.9 miles of graded road carrying 252 vehicles per day; and Phillips, with 7 miles of unimproved road carrying 388 vehicles per day.

Seven different surface widths were reported on Arkansas State highway routes as shown in table 3. Figure 2 shows the present surface width to scale, together with a symbol indicating the additional width necessary to bring the present pavement width up to 20 feet.

EIGHTY PERCENT OF ALL HIGHWAYS STUDIED CARRIED LESS THAN 500 VEHICLES PER DAY

Highways in Arkansas have also been classified in this report according to the amount of traffic carried. These classifications are: Major, medium, and minor.

Figure 3 shows the highways covered in the survey that carried 1,500 or more vehicles per day (major classification); those that carried 500 to 1,499 vehicles per day (medium classification); and those that carried under 500 vehicles per day (minor classification). The surveyed mileage on U. S. and State routes is summarized according to the above classifications in table 4.

There were some sections of Arkansas routes 17, 37, and 90 classified as unimproved that were reported as impassable on the days when traffic was counted at these points. These sections are indicated by a special symbol in figure 3. This figure also shows that a large mileage of Arkansas highways was in the minor classification.

Generally roads of major and medium classifications were main routes crossing Arkansas, more particularly

U S 61, routes from Memphis to Texarkana via Little Rock, and routes from Eudora to Fort Smith via Little Rock. Ark. 7 between Camden and El Dorado was of major classification. This is the only mileage with major classification not on the U. S. system. All of U S 71 between the Missouri Line and Fort Smith was of major or medium classification. U S 61 was the only route in Arkansas that was of major classification for its entire length.

TABLE 3.—*Surface widths of Arkansas State highways covered by the traffic survey*

Surface width (feet)	Miles of highway	Percentage of total
Over 26	585	7.3
26	[1] 5,143	63.9
20	244	3.0
18	1,343	16.7
16	[2] 354	4.4
14	353	4.4
9 (half width)	21	.3
Total	8,043	100.0

[1] Includes 4.5 miles that may be more or less than 26 feet.
[2] Includes 11 miles reported as impassable during survey counts.

TABLE 4.—*Classification of Arkansas State highway mileage covered by traffic survey*

Classification	Mileage	Percentage of total
Major	234	2.9
Medium	1,336	16.6
Minor	6,473	80.5
Total	8,043	100.0

There were long routes in Arkansas that had all or practically all of their mileage in the minor classification. This is true of U S 62, which is 344 miles in length including overlaps on other U S routes. There were 294 miles on this route with a traffic density of less than 500 vehicles per day. U S routes 79, 82, 165, 167, and 270 had most of their mileage in the minor classification.

Most of the mileage on State routes was of minor traffic classification. All of the 238 miles on Ark. 9 and 217 miles on Ark. 14 were of minor classification. About 206 miles of the major classification, or 88 percent were located on U. S. routes.

Traffic on a few sections that are reported to be of medium or minor classification may have had a traffic density of a higher classification at one end of the section, but the average traffic for the whole section was such as to place the particular mileage in the lower classification. An example is Ark. 45, which was of medium traffic classification at Fayetteville but of minor classification at the junction with Ark. 68.

ONE-FOURTH OF STATE HIGHWAY MILEAGE CARRIED NEARLY ONE-HALF OF THE TOTAL TRAFFIC

In each highway system there are concentrations of motor-vehicle traffic on certain roads generally referred to as trunkline highways, and as a result of the concentration of traffic a few routes stand out as the principal lanes of travel (fig. 4).

The most heavily traveled route through Arkansas extends from the Mississippi River bridge near Memphis, Tennessee, to Little Rock via U S 70 and thence via U S 67 to Texarkana. From the Mississippi River to Little Rock traffic averaged 1,725 vehicles per day, of which 39 percent was foreign. From Little Rock to Texarkana traffic averaged 1,137 vehicles per day, of which 36 percent was foreign. On this section at Benton there was a considerable change in density owing to the use of U S 70 by traffic going to Hot Springs National Park. The greatest traffic density along the route was recorded between West Memphis and Memphis—5,425 vehicles per day; and the lowest traffic density on this route was southwest of Malvern—752 vehicles per day.

The most heavily traveled intrastate route was U S 61 from the Missouri State line near Blytheville to West Memphis, over which traffic averaged 1,949 vehicles per day. The section on this route having the least traffic, north from Blytheville to the State line, had 1,452 vehicles per day. This is an especially heavy trucking route, averaging 419 trucks per day or nearly twice that of any other through route.

The principal highway connecting the two largest cities in Arkansas—Little Rock with a population of 81,679 and Fort Smith with 31,429—is the combination of U S 64 and U S 65 via Conway, Russellville, and Clarksville. All of this route has high-type surfacing, and over its 151 miles of length traffic averaged 1,106 vehicles per day. Between Russellville and Fort Smith, vehicles can use an alternate route—Ark. 22 with a portion of Ark. 7 and 27 via Dardanelle and Paris. This parallel highway is likewise of high-type surfacing with the exception of 3.3 miles between Russellville and Dardanelle. Traffic over this alternate route averaged 805 vehicles per day.

Little Rock is the commercial center of the State and the majority of the principal highways connect with this centrally located city like the spokes of a wheel. Also between Fort Smith and Rogers are concentrations of population which, combined with the interstate importance of route U S 71, gave roads in the northwest area considerable traffic. Traffic on U S 71 averaged 1,109 vehicles per day between the Missouri State line and Alma (junction of U S 71 and U S 64). The total traffic on this highway was practically equal to that on U S 64 and U S 65 between Little Rock and Fort Smith.

U S 70 from Benton west to the Oklahoma State line showed unusual variations in average traffic flow that were especially noticeable on the section between Benton and Hot Springs. This section carried an average traffic of 985 vehicles per day, while west of Hot Springs to the State line the traffic was 281 vehicles per day. The city of Hot Springs and Hot Springs National Park receive most of their traffic from the north and east.

The length of all routes illustrated in figure 4 totals 2,019 miles, or 25.1 percent of all roads covered by this survey. Their classification by traffic density groups is shown in table 5.

TABLE 5.—*Classification of principal through routes shown in figure 2 by density of traffic*

Vehicles per day	Selected through routes	Percentage of total
	Miles	
Under 250	190	9.4
250-499	732	36.3
500-1,499	897	44.4
Over 1,500	200	9.9
Total	2,019	100.0

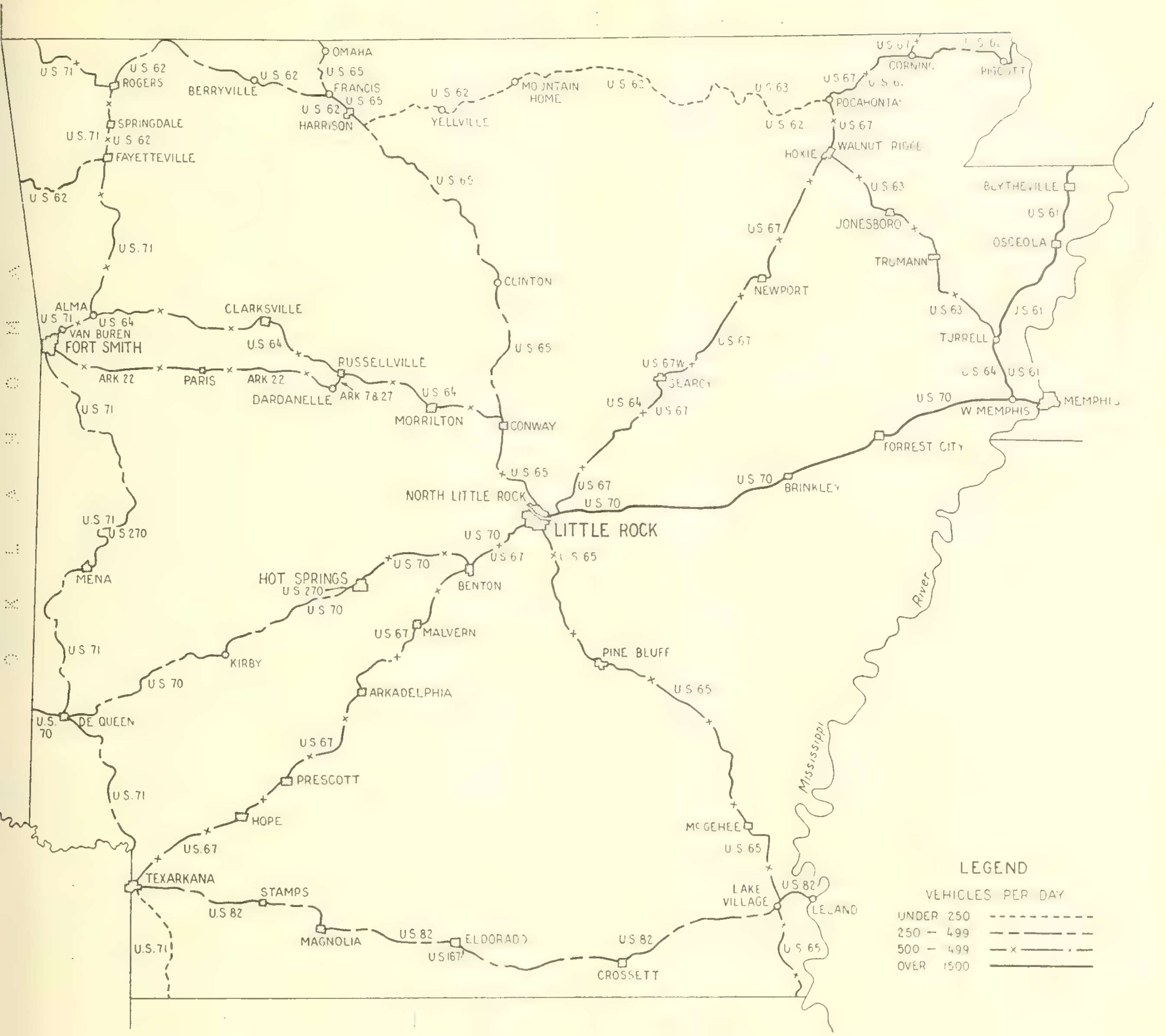

FIGURE 4.—PRINCIPAL THROUGH ROUTES CARRYING THE LARGEST VOLUMES OF TRAFFIC.

From this table it will be seen that approximately 0 percent of the through-route mileage carried a traffic n excess of 1,500 vehicles per day (major classification), and 46 percent carried a traffic of 500 or less ehicles per day (minor classification).

Travel upon the highways shown in figure 4 and sted in table 5 amounted to 1,450,000 vehicle-miles er day, or nearly 49 percent of that upon all roads overed by this survey. Thus, one-fourth of the State ighway mileage was carrying about one-half of the otal traffic.

Detailed data for a representative sample of truck, us, and passenger-car traffic were recorded at 25 stations in various parts of the State. These stations ere numbered consecutively from 1 to 25.

SPECIAL STUDIES CONDUCTED AT 25 STATIONS

These 25 stations were located on the main thoroughares of the State and in the vicinity of Little Rock nd other principal cities. Stations 1, 3, 8, 10, and 19 were located on U S 67 which traverses the State from northeast to southwest. Stations 2 and 4 were on U S 63 and 64, respectively. Stations 5 and 7 were on U S 70 between Memphis, Tenn., and Little Rock. Station 6 was on U S 79 between Memphis and Pine Bluff. Station 23 was near Fort Smith on Ark. 22, which converges at Russellville with U S 64 and thence joins U S 65 north of Conway. Stations 9, 12, 13, and 14 were on U S 65, which crosses the State from northwest to southeast, and stations 11, 15, and 16 were on U S 167 which runs south from Little Rock to El Dorado and the Louisiana border. Station 17 was between El Dorado and Texarkana on U S 82, the southernmost east-west highway of the State. Stations 25, 24, 22, 21, 20, and 18 were on U S 71, the principal north-south highway in the western part of the State. In the tables that show figures for individual stations, the stations are listed in the order outlined above.

The information relating to truck, bus, and passenger-car traffic recorded at these 25 stations included the State of registration of each vehicle; its origin and destination on the current trip; the situs of ownership, whether farm or city, the latter class being subdivided into private and company ownership; and the trip classification, whether State, interstate, or trans-State. Information was also obtained regarding the operation of trucks and busses, whether privately operated or operated as contract haulers or common carriers; and the extent of contact of trucks and busses with railroad service, that is, whether they stopped or started at a railroad station. The nature of the load carried, rated capacity, and gross axle and trailer loads of trucks, and the number of passengers carried by busses at the time of questioning, were also recorded.

The difference between the totals in the individual tables results from the fact that every item of information was not obtained for all vehicles. Since the size of the samples used in the tables varies slightly, actual numbers should be used only in connection with those in the analysis in which they occur. Percentages, however, which represent general relations, may be used without this restriction.

Certain terms that are used in the following tables are defined as follows:

Trip classifications: *State*—a trip on which the vehicle did not cross the boundaries of Arkansas; *interstate*—a trip on which the vehicle had one terminus in Arkansas and crossed the boundaries of the State en route. In some cases both the origin and destination were within the State. *Trans-State*—a trip on which the vehicle passed through Arkansas en route between points in other States.

Classes of operation: *Private operator*—a vehicle operated by its owner or his employee in the pursuit of the owner's private business, as distinguished from the two classes of commercial vehicles engaged in hauling for others for hire; *contract hauler*—a vehicle that makes special trips when and where desired, at rates agreed upon by the contracting parties; *common carrier*—a vehicle that followed established routes between fixed points, and operated on a regular schedule at standard published rates.

Capacities of trucks—Manufacturers' rated capacities are sometimes combined into the following groups: *Light*—1½ tons and under; *medium*—between 1½ and 3 tons; *heavy*—3 tons and over.

Nature of load carried: *Manufactured products*—wholesale deliveries, automobile parts, newspapers, or any other class of manufactured commodities; *agricultural products*—all unprocessed products of agriculture, including milk, livestock, etc.; *mineral products* — coal, marble, oil, gasoline, etc.; *forest products* — lumber, trees, shrubs, etc.; *household goods* — furniture in moving vans, etc., excluding new furniture which belongs with manufactured products; *highway materials*—State highway trucks, construction materials, etc.

Definitions of vehicle-units: *Trailer*—any trailer or semitrailer without distinction as to size or type of unit; *single-unit trucks*—trucks of which both engine and body were supported by a single chassis; *truck-trailer combinations*—a motor unit to which full or semitrailer units were attached.

Daily motor traffic at these 25 stations between April 1934 and June 1935 averaged 26,848 vehicles per day, of which 80.2 percent were passenger cars, 18.7 percent trucks, and 1.1 percent busses. An average of only about one truck per thousand was recorded as making contact with railroad service, the range among individual stations being from one to five trucks per thousand. An average of 29 busses per hundred recorded made contact with railroad service by having one or the other (or both) of their terminals at a railroad station. Busses making such contact varied from 2 to 75 percent of those recorded at individual stations.

Approximately three out of four vehicles of all kinds carried Arkansas registration plates. A greater percentage of trucks and busses than of passenger cars carried such tags. A little less than two out of three vehicles of all types were owned by individuals living in cities, one out of four by city companies, and one out of nine by farmers. Six out of 10 vehicles were engaged in State traffic, almost 3 out of 10 in interstate traffic, and about 1 out of 11 in trans-State traffic.

CLASSIFICATION OF LOADS CARRIED BY TRUCKS DISCUSSED

The classification of single-unit trucks and of truck-trailer combinations according to whether they were loaded or empty at the time of questioning, and according to the designated type of load carried, is presented in table 6.

Sixty-one percent of all trucks recorded at 25 stations were loaded, and 39 percent were empty. Manufactured products comprised the loads of more than one-half of the loaded trucks. One out of 5 of the loaded trucks carried agricultural products and 1 out of 1 carried passengers. Next in importance as truck loads were mineral and forest products, followed by household goods, highway materials, and retail delivery in the order named.

TABLE 6.—*Classification of single-unit trucks and trucks wit trailers recorded at 25 stations, by nature of load carried*

Nature of load carried	Single-unit trucks		Truck-trailer combinations		All trucks		Percentage of combinations with only one trailer
	Number	Percentage of grand total	Number	Percentage of grand total	Number	Percentage of grand total	
Commercial commodities:							
Manufactured products	8,180	29.1	2,243	39.7	10,423	30.8	98 3
Agricultural products	3,393	12.1	720	12.8	4,113	12.2	99 4
Mineral products, oil	1,264	4.5	82	1.5	1,346	4.0	100 0
Forest products	724	2.6	465	8.2	1,189	3.5	100
Retail delivery	90	.3	------	------	90	.3	------
Total	13,651	48.6	3,510	62.2	17,161	50.8	99 1
Other types of load:							
Passengers	1,947	6.9	57	1.0	2,004	5.9	10
Household goods	626	2.2	76	1.3	702	2.1	10
Highway materials	560	2.0	32	.6	592	1.8	10
Total	3,133	11.1	165	2.9	3,298	9.8	10
All types of load	16,784	59.7	3,675	65.1	20,459	60.6	9
Empty	11,351	40.3	1,971	34.9	13,322	39.4	9
Grand total	28,135	100.0	5,646	100.0	33,781	100.0	9

A greater percentage of truck-trailer combinatio than of single-unit trucks carried manufactured pro ucts, although the actual number of single-unit truc carrying this class of commodities was almost fo times as great as that of truck-trailer combination About the same percentage of each type of truc carried agricultural products. A greater percentage single-unit trucks carried mineral products, such coal, marble, oil, and gasoline, while a much great percentage of trucks with trailers carried forest pro ucts. Only single-unit trucks were recorded as making retail delivery, and there were comparatively few of these. Since the stations at which these traffic samples were taken were usually in the outskirts or entirely outside of commercial centers, the low percentage of retail delivery trucks indicates the infrequency of this type of transportation in outlying areas of Arkansas.

These five groups of products have been combined into a major group, called commercial commodities, as distinguished from other types of loads, such as passengers, used household goods, and State highway trucks. Almost 49 percent of all single-unit trucks and more than 62 percent of trucks with trailers were carrying commercial commodities. The corresponding percentages for all other types of load were about 11 and 3 percent, respectively.

The frequency distribution of busses carrying various numbers of passengers is given in table 7. The average number of passengers carried by busses in each frequency group is also shown.

TABLE 7.—*Classification of busses recorded at 25 stations, by number of passengers carried*

Number of passengers	Number of busses	Percentage of total	Cumulative percentage	Average number of passengers
None	196	8.7	8.7	0.0
1 to 5	564	25.0	33.7	3.0
6 to 10	494	21.9	55.6	7.8
11 to 15	325	14.4	70.0	13.0
16 to 20	252	11.2	81.2	17.6
21 to 25	166	7.3	88.5	22.8
26 to 30	124	5.5	94.0	28.1
31 to 35	61	2.7	96.7	33.0
36 to 40	35	1.5	98.2	38.3
41 to 45	16	.7	98.9	44.1
46 to 50	18	.8	99.7	49.1
More than 50	8	.3	100.0	59.4
Total	2,259	100.0		11.9

Among busses that operated exclusively within the State, there were about three contract-hauler busses, including hired school busses, chartered busses, and the like to every seven common-carrier busses. Comparatively few contract-hauler busses were found in interstate or trans-State traffic, more than 9 out of 10 of these being common carriers.

More than half of the privately owned busses were contract haulers, but only about 4 percent of company owned busses were engaged in this class of operation. The principal business of company owned busses was that of serving the public as common carriers.

EIGHTY-NINE PERCENT OF ALL BUSSES CARRIED 25 PASSENGERS OR LESS

From the average daily density of truck traffic and the average gross weight of trucks recorded at each of the 25 stations, the estimated total gross weight of daily truck traffic, including both single-unit trucks and truck-trailer combinations, have been derived. These data are presented in table 8.

The average gross weight of all single-unit trucks recorded at the 25 stations was 6,270 pounds. The gross weight of loaded single-unit trucks was 7,390 pounds, and that of empty trucks of this type was 4,550 pounds. The corresponding average gross weights of truck-trailer combinations were 15,040 pounds, 18,320 pounds, and 8,920 pounds, respectively. Thus, loaded trailer combinations weighed about two and one-half times as much as loaded single-unit trucks, and empty trailer combinations about twice as much as empty single-unit trucks. The average net load of single-unit trucks was 2,840 pounds, and that of trailer combinations was 9,400 pounds, the latter being more than three times as great as the former.

TABLE 8.—*Estimated total gross weight of daily truck traffic recorded at 25 stations*

Station number	Location of station	Average daily truck traffic	Average gross weight per truck	Estimated daily gross weight: Weight	Estimated daily gross weight: Percentage of total
		Number	*Pounds*	*Pounds*	
1	U S 67 and 62 at Corning	130	6,180	803,400	2.2
3	U S 67 and Ark. 14 west of Newport	102	6,680	681,360	1.8
8	U S 67 northeast of North Little Rock	228	6,390	1,456,920	4.0
10	U S 67 and 70 southwest of Little Rock	320	7,280	2,329,600	6.3
19	U S 67 northeast of Fulton	103	7,180	739,540	2.0
2	U S 63 and Ark. 9 at Mammoth Springs	145	5,330	772,850	2.1
4	U S 64 west of Augusta	38	8,720	331,360	.9
5	U S 70 east of West Memphis	988	8,750	8,645,000	23.4
7	U S 70 at De Valls Bluff	130	11,140	1,448,200	3.9
6	U S 79 at Roe	32	8,910	285,120	.8
23	Ark. 22 east of Ft. Smith	196	7,340	1,438,640	3.9
9	U S 65 and 64 north of Conway	398	7,670	3,052,660	8.3
12	U S 65 south of Little Rock	120	7,920	950,400	2.6
13	U S 65 and Ark. 13 east of Pine Bluff	189	7,190	1,358,910	3.7
14	U S 65 and 165 southeast of McGehee	244	5,700	1,390,800	3.8
11	U S 167 south of Little Rock	106	6,430	681,580	1.8
15	U S 167 northeast of El Dorado	28	8,280	231,840	.6
16	U S 167 and 82 southeast of El Dorado	170	5,930	1,008,100	2.7
17	U S 82 at Garland City	41	8,200	336,200	.9
25	U S 71 and 62 west of Rogers	471	6,570	3,094,470	8.4
24	U S 71 and 64 at Alma	435	7,160	3,114,600	8.5
22	U S 71 southeast of Ft. Smith	180	6,580	1,184,400	3.2
21	U S 71 and 270 northeast of Mena	63	7,040	443,520	1.2
20	U S 71 south of Ogden	100	7,140	714,000	1.9
18	U S 71 southeast of Texarkana	65	6,410	416,650	1.1
	Average or total	5,022	7,350	36,910,120	100.0

The average gross weights of trucks, according to rated capacity groups were as follows: Loaded single-unit trucks—light, 6,830 pounds; medium, 13,040 pounds; and heavy, 19,880 pounds: Empty single-unit trucks—light, 4,310 pounds; medium, 8,660 pounds; and heavy, 15,740 pounds. These figures indicate that an average net load of 2,520 pounds was carried by light trucks of this type, 4,380 pounds by medium-size trucks, and 4,140 pounds by heavy trucks, the heaviest average net load being carried by medium-size trucks.

DATA ON AXLE LOADS AND TOTAL GROSS LOADS OF TRUCKS PRESENTED

The total gross weights of single-unit trucks and truck-trailer combinations ranged as follows: From 1,000 to 20,000 pounds for empty single-unit trucks, with a median between 4,000 and 5,000 pounds; from 1,000 to 42,000 pounds for empty truck-trailer combinations, with a median between 8,000 and 9,000 pounds; from 1,000 to 33,000 pounds for loaded single-unit trucks, with a median between 6,000 and 7,000 pounds; and from 2,000 to 67,000 pounds for loaded truck-trailer combinations, with a median between 18,000 and 19,000 pounds. The median group in each series represents the point so chosen that half the number in the series were above and half below it. In each group the presence of a few very heavy trucks was balanced by a larger number in the lighter-weight groups. The greatest average gross weight of loaded single-unit trucks was found among those carrying forest products, and the average gross weight of those loaded with mineral products was almost as great. Among truck-trailer combinations, however, trucks having the greatest average gross weights carried manufactured or agricultural products.

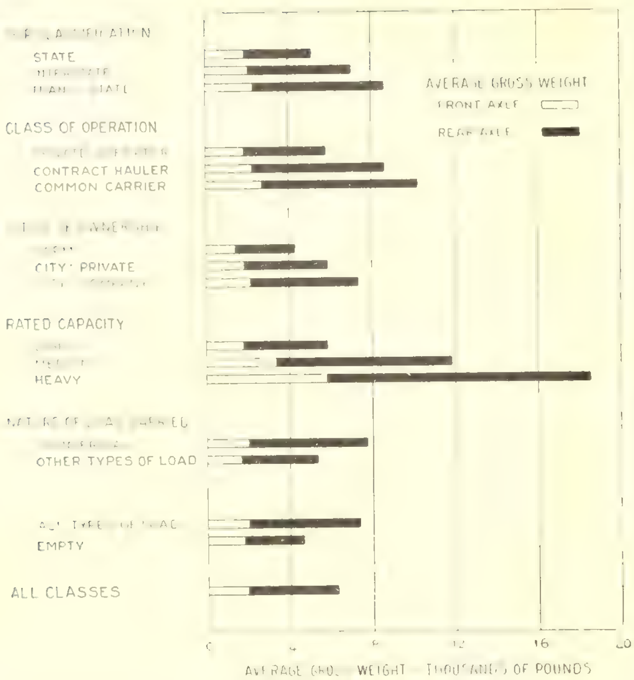

FIGURE 5.—AVERAGE GROSS AXLE LOADS OF TRUCKS RECORDED AT 25 STATIONS BY VARIOUS CLASSIFICATIONS.

Average gross axle and total loads of trucks according to trip, operation, and ownership classifications, rated capacity, and nature of load carried, are presented in tables 9 to 12 inclusive. The principal items are also shown graphically in figure 5.

TABLE 9.—*Number and average axle loads of trucks recorded at 25 stations, by various classifications*

Classification	Number of trucks	Average gross loads [1]				
		Front axle		Rear axle		
		Weight	Percentage of total weight	Weight	Percentage of total weight	Total weight
		Pounds		*Pounds*		*Pounds*
Trip classification:						
State	23,584	1,880	32.4	3,930	67.6	5,810
Interstate	9,107	2,070	29.0	5,060	71.0	7,130
Trans-State	1,210	2,310	26.9	6,290	73.1	8,600
Total	33,901	1,950	31.1	4,320	68.9	6,270
Class of operation:						
Private operator	28,763	1,870	32.5	3,890	67.5	5,760
Contract hauler	3,460	2,260	26.2	6,360	73.8	8,620
Common carrier	1,568	2,740	26.3	7,680	73.7	10,420
Total	33,791	1,950	31.1	4,320	68.9	6,270
Situs of ownership:						
Farm	5,892	1,510	35.4	2,750	64.6	4,260
City—Private	12,628	1,830	31.1	4,050	68.9	5,880
City—Company	15,313	2,210	30.1	5,140	69.9	7,350
Total	33,833	1,950	31.1	4,320	68.9	6,270
Rated capacity:						
Light	31,383	1,820	31.3	4,000	68.7	5,820
Medium	2,395	3,460	29.3	8,340	70.7	11,800
Heavy	84	5,920	32.1	12,510	67.9	18,430
Total	33,862	1,950	31.1	4,320	68.9	6,270
Nature of load carried.						
Commercial	17,161	2,080	26.7	5,690	73.3	7,770
Other types of load	3,298	1,770	33.1	3,580	66.9	5,350
All types of load	20,459	2,030	27.5	5,360	72.5	7,390
Empty	13,322	1,820	40.0	2,730	60.0	4,550
Total	33,781	1,950	31.1	4,320	68.9	6,270

[1] Represents gross weights of motor trucks, excluding trailers.

TABLE 10.—*Number and average axle loads of trucks recorded at 25 stations on Arkansas highways, by nature of load carried*

Nature of load carried	Number of trucks	Average gross loads [1]				
		Front axle		Rear axle		
		Weight	Percentage of total load	Weight	Percentage of total load	Total weight
Commercial commodities:		*Pounds*		*Pounds*		*Pounds*
Manufactured products	10,423	2,130	28.1	5,440	71.9	7,570
Agricultural products	4,113	1,960	25.0	5,880	75.0	7,840
Mineral products, oil	1,346	2,260	26.8	6,160	73.2	8,420
Forest products	1,189	1,930	21.7	6,970	78.3	8,900
Retail delivery	90	1,410	38.2	2,280	61.8	3,690
Total	17,161	2,080	26.7	5,690	73.3	7,770
Other types of load:						
Passengers	2,004	1,590	36.8	2,740	63.2	4,330
Household goods	702	1,810	28.1	4,630	71.9	6,440
Highway materials	592	2,330	30.9	5,200	69.1	7,530
Total	3,298	1,770	33.1	3,580	66.9	5,350
All types of load	20,459	2,030	27.5	5,360	72.5	7,390
Empty	13,322	1,820	40.0	2,730	60.0	4,550
Grand total	33,781	1,950	31.1	4,320	68.9	6,270

[1] Represents gross weights of motor trucks, excluding trailers.

TABLE 11.—*Number and average axle loads of empty trucks recorded at 25 stations, by rated capacity*

Rated capacity	Number of trucks	Average gross loads [1]				
		Front axle		Rear axle		
		Weight	Percentage of total load	Weight	Percentage of total load	Total weight
		Pounds		*Pounds*		*Pounds*
½ ton [2]	4,757	1,390	47.3	1,550	52.7	2,940
1 ton [3]	644	1,440	41.0	2,070	59.0	3,510
1½ tons	7,217	1,990	37.6	3,300	62.4	5,290
2 tons	444	2,860	37.0	4,860	63.0	7,720
2½ tons	41	3,420	38.6	5,430	61.4	8,850
3 tons	131	3,870	37.5	6,450	62.5	10,320
3½ tons	52	4,760	40.5	6,980	59.5	11,740
4 tons	7	4,770	36.5	8,300	63.5	13,070
5 tons	26	5,840	37.1	9,900	62.9	15,740
Capacity groups: [4]						
Light	12,618	1,740	40.4	2,570	59.6	4.310
Medium	675	3,260	37.6	5,400	62.4	8,660
Heavy	26	5,840	37.1	9,900	62.9	15,740
All capacities	13,319	1,820	40.0	2,730	60.0	4,550

[1] Represents gross weights of motor trucks, excluding trailers.
[2] Includes two ¼-ton trucks.
[3] Includes two ¾-ton trucks.
[4] Light, 1½ tons and under; medium, between 1½ and 5 tons; heavy, 5 tons and over.

The average gross total weight of all trucks was 6,270 pounds, or a little more than 3 tons. The average gross weight on the front axles of all trucks was 1,950 pounds, and that on the rear axles was 4,320 pounds, representing 31.1 percent and 68.9 percent of the total, respectively.

The percentage of average gross weight carried by the front axle of trucks, grouped according to rated capacity, was greatest for heavy trucks and least for those of medium capacity. The corresponding percentage for trucks loaded with commercial commodities was smaller than that for those carrying other types of load. The percentages of the average total gross loads carried by front and rear axles were 27.5 and 72.5 percent for loaded and 40 and 60 percent for empty trucks.

TABLE 12.—*Number and average axle loads of loaded trucks recorded at 25 stations, by rated capacity*

Rated capacity	Number of trucks	Average gross loads[1]				
		Front axle		Rear axle		Total weight
		Weight	Percentage of total load	Weight	Percentage of total load	
		Pounds		*Pounds*		*Pounds*
½ ton[2]	5,660	1,390	39.4	2,140	60.6	3,530
1 ton[3]	1,079	1,500	30.0	3,500	70.0	5,000
1½ tons	12,026	2,150	25.1	6,400	74.9	8,550
2 tons[4]	1,174	3,160	26.3	8,870	73.7	12,030
2½ tons[5]	174	3,920	29.2	9,510	70.8	13,430
3 tons	271	4,290	27.4	11,370	72.6	15,660
3½ tons	77	5,710	32.6	11,780	67.4	17,490
4 tons	24	4,260	27.7	11,120	72.3	15,380
5 tons[6]	58	6,010	30.2	13,870	69.8	19,880
Capacity groups:[7]						
Light	18,765	1,880	27.5	4,950	72.5	6,830
Medium	1,720	3,550	27.2	9,490	72.8	13,040
Heavy	58	6,010	30.2	13,870	69.8	19,880
All capacities	20,543	2,030	27.5	5,360	72.5	7,390

[1] Represents gross weights of motor trucks, excluding trailers.
[2] Includes one ¼-ton truck.
[3] Includes six ¾-ton trucks.
[4] Includes one 1¾-ton truck.
[5] Includes one 2¼-ton truck.
[6] Includes one 7½-ton truck.
[7] Light, 1½ tons and under; medium, between 1½ and 5 tons, heavy, 5 tons and over.

LIGHT TRUCKS HAD GREATEST TENDENCY TO EXCEED RATED CAPACITY

The greatest average gross weight of trucks classified according to the nature of load carried was found among those which carried forest products, mineral products, such as coal, oil, marble and similar products, and agricultural products. Trucks carrying these three groups of commodities also showed a smaller percentage of the total weight carried by the front axle than that of other groups, indicating that net loads of these commodities were relatively heavier, and that the loaded weight was concentrated principally on the rear axle. Retail delivery trucks and trucks carrying passengers showed a relatively greater proportion of the total gross load carried by the front axle, and trucks carrying manufactured products, including wholesale delivery trucks, as well as household goods and highway materials, were in an intermediate position.

Average gross weights of trucks, classified according to rated capacity, are shown in tables 11 and 12. For empty trucks, both total and individual axle weights of these groups showed an approximately straight-line increase which varied directly with the increasing rated capacity. The few minor irregularities which appear in these series were caused in part by the small number of trucks in the samples for certain groups. But still another factor must be considered, that is, the inclusion in these samples of trucks of any and all makes, some of which were of light and some of extremely heavy construction, with many gradations between. The majority of trucks in the lowest rated capacity groups were of the lighter makes, and those in the 1½-ton capacity group, also, were principally of this type, while most, if not all, of the trucks of 5-tons capacity or over were of the more heavily built makes. In the intervening group, however, in addition to trucks of moderately heavy construction, there were some of the heavier trucks of lighter makes, and a scattering of the lighter trucks of heavy makes, thus producing a composite group which does not conform to any of the types of which it is partly composed.

In the case of loaded trucks there are even more factors affecting the composition of the sample. Here, in addition to the differences between the vehicles themselves, the variation in the nature and weight of loads carried is also involved. Despite these divergent elements, the average total and axle weights of trucks, arranged in increasing order by rated capacity, show a comparatively regular increase, with the exception of the 4-ton capacity group, at which a marked break occurs in each series. This may be ascribed to the fact that the number of trucks in this capacity group is not sufficiently large to give a true average. The inadequacy of this group is shown in the frequency distribution.

Although the net weight of loads carried by individual trucks was not obtained in connection with this survey, it is possible to arrive at an approximate average net weight of loads by subtracting the weight of empty trucks from that of loaded trucks of corresponding rated capacity groups. This method has been followed in obtaining the figures presented in the third column of table 13.

The average net weight of loads increased with increase in rated capacity, but at a lesser rate than the capacity itself, up to the 4- and 5-ton groups, for which the computed average net loads were smaller than those for the 1½- and 2-ton groups, respectively. The greatest average net load was carried by 3- and 3½-ton trucks. Trucks of light rated capacity carried relatively heavier net loads, and heavy trucks relatively lighter net loads, in comparison with their capacity. The average net load of trucks of all capacities was about 1.1 times the average rated capacity.

TABLE 13.—*Average gross and net loads of trucks of each rated capacity recorded at 25 stations, and ratio to rated capacity*

Rated capacity	Average gross weight[1]		Average net weight[1]	Ratio of rated capacity to—	
	Loaded trucks	Empty trucks		Average loaded weight	Average net weight
	Pounds	*Pounds*	*Pounds*		
½ ton	3,530	2,940	590	1:3.5	1:0.6
1 ton	5,000	3,510	1,490	1:2.5	1:0.8
1½ tons	8,550	5,290	3,260	1:2.9	1:1.1
2 tons	12,030	7,720	4,310	1:3.0	1:1.1
2½ tons	13,430	8,850	4,580	1:2.6	1:0.9
3 tons	15,660	10,320	5,340	1:2.6	1:0.9
3½ tons	17,490	11,740	5,750	1:2.5	1:0.8
4 tons	15,380	13,070	2,310	1:1.9	1:0.3
5 tons	19,880	15,740	4,140	1:2.0	1:0.4
Capacity groups:[2]					
Light[3]	6,830	4,310	2,520	1:3.0	1:1.1
Medium[4]	13,040	8,660	4,380	1:2.9	1:1.0
Heavy[5]	19,880	15,740	4,140	1:2.0	1:0.4
All capacities[6]	7,390	4,550	2,840	1:3.0	1:1.1

[1] Represents weights of motor trucks, excluding trailers.
[2] Light, 1½ tons and under; medium, between 1½ and 5 tons, heavy, 5 tons and over.
[3] Average about 1⅛ tons.
[4] Average about 2¼ tons.
[5] Average about 5 tons.
[6] Average about 1¼ tons.

SEVEN-EIGHTHS OF ALL LOADED TRUCKS WEIGHED LESS THAN 6 TONS

The frequency distributions of empty and loaded trucks of various capacities, according to average total gross-weight groups, are presented in tables 14

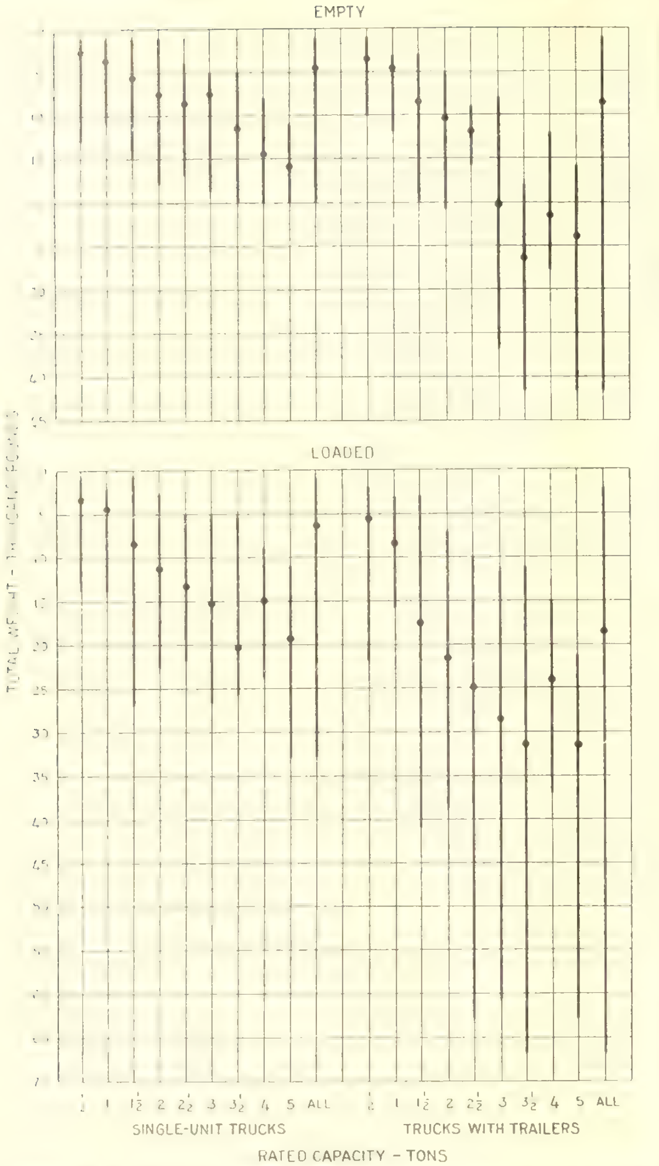

Figure 6.—Total Gross Weights of Empty and Loaded Single-Unit Trucks and Trucks With Trailers of Each Rated Capacity, Showing Range and Median Point.

and 15. Figure 6 gives this same information in graphic form, showing the range and median point among weights of trucks of each rated capacity. This figure also includes corresponding information relating to trucks with trailers. In the tables, actual numbers have been converted to the number of trucks per thousand in the sample for each class, respectively, thus making possible general comparisons in each table. These figures can be converted into percentages by placing a decimal point in front of the last digit of each.

Table 14.—*Frequency distribution of empty trucks recorded at 25 stations by rated capacity and total weight groups*

Total weight	Number of trucks per thousand in sample for rated capacities of—									
	½ ton [1]	1 ton [2]	1½ tons	2 tons	2½ tons	3 tons	3½ tons	4 tons	5 tons	All capacities
Pounds										
1,000- 1,999	11	1	(3)	(3)	----	----	----	----	----	12
2,000- 2,999	173	14	3	(3)	----	----	----	----	----	190
3,000- 3,999	161	20	55	(3)	----	----	----	----	----	236
4,000- 4,999	10	10	155	1	(3)	----	----	----	----	177
5,000- 5,999	1	2	200	4	(3)	1	(3)	----	----	209
6,000- 6,999	(3)	1	89	7	(3)	1	(3)	----	----	98
7,000- 7,999	(3)	(3)	24	9	(3)	1	(3)	----	----	36
8,000- 8,999	(3)	(3)	9	5	(3)	1	(3)	(3)	----	15
9,000- 9,999	(3)	----	4	4	(3)	1	----	(3)	----	9
10,000-10,999	----	(3)	1	2	1	1	----	----	----	5
11,000-11,999	----	----	1	(3)	(3)	(3)	2	(3)	(3)	4
12,000-12,999	(3)	----	(3)	1	(3)	1	(3)	----	(3)	2
13,000-13,999	----	----	(3)	(3)	(3)	1	(3)	----	(3)	2
14,000-14,999	----	----	(3)	(3)	----	1	(3)	(3)	(3)	2
15,000-15,999	----	----	----	(3)	----	(3)	(3)	----	(3)	1
16,000-16,999	----	----	----	(3)	(3)	(3)	(3)	----	(3)	1
17,000-17,999	----	----	----	(3)	----	(3)	(3)	----	(3)	1
18,000-18,999	----	----	----	----	----	(3)	----	----	(3)	(3)
19,000-19,999	----	----	----	----	----	----	(3)	(3)	(3)	(3)
All weight groups	357	48	542	33	3	10	4	1	2	1,000

[1] Includes two ¼-ton trucks.
[2] Includes two ¾-ton trucks.
[3] Less than one per thousand.

Table 15.—*Frequency distribution of loaded trucks recorded at 25 stations, by rated capacity and total weight groups*

Total weight	Number of trucks per thousand in sample for rated capacities of—									
	½ ton [1]	1 ton [2]	1½ tons	2 tons [3]	2½ tons [4]	3 tons	3½ tons	4 tons	5 tons [5]	All capacities
Pounds										
1,000- 1,999	4	----	(6)	----	----	----	----	----	----	4
2,000- 2,999	60	4	1	----	----	----	----	----	----	65
3,000- 3,999	140	12	9	(6)	----	----	----	----	----	162
4,000- 4,999	56	14	36	(6)	----	----	----	----	----	106
5,000- 5,999	12	10	74	1	(6)	(6)	(6)	----	----	97
6,000- 6,999	2	6	77	2	(6)	(6)	(6)	----	----	88
7,000- 7,999	(6)	3	77	3	(6)	(6)	(6)	----	----	84
8,000- 8,999	(6)	2	74	4	(6)	(6)	(6)	----	----	82
9,000- 9,999	(6)	1	66	6	(6)	1	----	(6)	----	74
10,000-10,999	(6)	(6)	50	6	1	(6)	(6)	(6)	----	58
11,000-11,999	(6)	(6)	41	7	1	1	(6)	(6)	(6)	50
12,000-12,999	(6)	(6)	29	5	(6)	1	(6)	(6)	----	37
13,000-13,999	(6)	(6)	22	5	1	1	(6)	(6)	(6)	29
14,000-14,999	----	----	14	5	1	1	----	(6)	(6)	21
15,000-15,999	----	----	8	4	1	1	(6)	----	(6)	14
16,000-16,999	----	----	4	3	1	1	(6)	(6)	(6)	9
17,000-17,999	----	----	1	2	(6)	1	(6)	(6)	(6)	5
18,000-18,999	----	----	1	2	(6)	1	(6)	(6)	(6)	5
19,000-19,999	----	----	(6)	1	(6)	1	(6)	(6)	(6)	3
20,000-20,999	----	----	----	1	(6)	(6)	2	(6)	(6)	4
21,000-21,999	----	----	----	(6)	(6)	1	(6)	----	(6)	2
22,000-22,999	----	----	(6)	(6)	----	(6)	(6)	(6)	(6)	1
23,000-23,999	----	----	----	----	----	(6)	----	(6)	(6)	(6)
24,000-24,999	----	----	----	----	----	----	----	----	(6)	(6)
25,000-25,999	----	----	----	----	----	----	(6)	----	(6)	(6)
26,000-26,999	----	----	(6)	----	----	(6)	----	----	----	(6)
27,000-27,999	----	----	----	----	----	----	----	----	----	----
28,000-28,999	----	----	----	----	----	----	----	----	----	----
29,000-29,999	----	----	----	----	----	----	----	----	(6)	(6)
30,000-30,999	----	----	----	----	----	----	----	----	----	----
31,000-31,999	----	----	----	----	----	----	----	----	(6)	(6)
32,000-32,999	----	----	----	----	----	----	----	----	(6)	(6)
All weight groups	276	53	585	57	8	13	4	1	3	1,000

[1] Includes one ¼-ton truck.
[2] Includes six ¾-ton trucks.
[3] Includes one 1¾-ton truck.
[4] Includes one 2¼-ton truck.
[5] Includes one 7½-ton truck.
[6] Less than one per thousand.

GROSS LOADS OF TRUCKS WITH TRAILERS GENERAL CLASSIFICATIONS

Average gross axle and trailer loads of truck-trailer combinations, according to trip, operation, and ownership classifications, are presented in table 16. Corresponding figures for trucks with trailers which carried loads of various kinds are shown in table 17. A comparison of the relative importance of front axle, rear axle, and trailer loads in each of these classifications is shown graphically in figure 7.

Special information with regard to foreign passenger-car traffic was obtained at survey stations near the Arkansas border during the regular operations of these stations.

The special information was obtained from post-card questionnaires requiring no postage, distributed to foreign passenger-car operators at border stations. The driver was asked to give the following data: (1) Whether trip was for business or pleasure; (2) number of occupants of the car; (3) number of miles driven in Arkansas; (4) number of days stay in Arkansas; (5) type of accommodation used, such as hotels, tourist camps, etc., or "driving through"; and (6) State in which the car was registered.

Approximately 6,500 cards were returned, or 28 percent of those distributed. The number of cards returned ranged from 22 to 39 percent of those distributed at individual stations.

SEVENTY-FIVE PERCENT OF FOREIGN PASSENGER-CAR TRAFFIC ORIGINATED IN FIVE ADJACENT STATES

Table 18 shows the average daily and annual foreign passenger-car traffic at 51 stations located near the Arkansas border.

Foreign passenger-car traffic recorded at these points was used in computing the daily and annual traffic entering and leaving Arkansas. At the 51 stations shown in table 18 a total annual traffic of 2,983,800 foreign passenger cars was estimated to have entered or left Arkansas during the year. Half of this traffic, 1,491,900 vehicles, was assumed to have entered the State.

Since the tourist traffic entering or leaving Arkansas is not concentrated during any period of the year, the foreign passenger-car traffic entering the State was assumed to have had the same seasonal variation as all foreign passenger-car traffic recorded within the State.

The State of registration as determined from license tags provided a means of accurately estimating the volume of foreign passenger-car traffic by State of origin.

The origin of tourist traffic—foreign passenger-car traffic—is summarized by areas in table 19. In figure 8 the areas within the circles show the relative volume of tourist traffic originating in each geographical section.

TABLE 16.—*Number and average axle and trailer loads of trucks with trailers recorded at 25 stations, by various classifications*

Classification	Number of truck trailer combinations	Average gross loads						
		Truck				Trailer		Total weight
		Front axle		Rear axle				
		Weight	Percentage of total load	Weight	Percentage of total load	Weight	Percentage of total load	
Trip classification:		*Pounds*		*Pounds*		*Pounds*		*Pounds*
State	2,900	2,310	16.8	6,260	45.6	5,170	37.6	13,740
Interstate	2,281	2,360	14.7	7,200	44.9	6,480	40.4	16,040
Trans-State	476	2,610	14.4	8,170	44.9	7,400	40.7	18,180
Total	5,657	2,360	15.7	6,800	45.2	5,880	39.1	15,040
Class of operation:								
Private operator	2,863	2,190	16.9	5,920	45.6	4,860	37.5	12,970
Contract hauler	1,836	2,300	14.7	7,160	45.5	6,250	39.8	15,710
Common carrier	951	2,960	14.9	8,750	43.9	8,220	41.2	19,930
Total	5,650	2,360	15.7	6,800	45.2	5,880	39.1	15,040
Situs of ownership:								
Farm	219	1,820	19.2	4,270	45.0	3,400	35.8	9,490
City—Private	2,100	2,050	16.0	5,900	46.0	4,870	38.0	12,820
City—Company	3,335	2,590	15.4	7,530	44.8	6,680	39.8	16,800
Total	5,654	2,360	15.7	6,800	45.2	5,880	39.1	15,040

TABLE 17.—*Number and average axle and trailer loads of trucks with trailers recorded at 25 stations, by nature of load carried*

Nature of load carried	Number of truck trailer combinations	Average gross loads						
		Truck				Trailer		Total weight
		Front axle		Rear axle				
		Weight	Percentage of total load	Weight	Percentage of total load	Weight	Percentage of total load	
Commercial commodities.		*Pounds*		*Pounds*		*Pounds*		*Pounds*
Manufactured products	2,243	2,580	13.7	8,620	45.5	7,730	40.8	18,930
Agricultural products	720	2,230	11.9	8,480	45.3	8,020	42.8	18,730
Mineral products, oil	82	2,360	13.3	8,050	45.5	7,300	41.2	17,710
Forest products	465	2,070	11.8	8,310	47.4	7,130	40.8	17,510
Total	3,510	2,440	13.1	8,540	45.7	7,690	41.2	18,670
Other types of load:								
Passengers	57	2,000	23.6	4,050	47.6	2,450	28.8	8,500
Household goods	76	2,040	17.7	5,370	46.6	4,120	35.7	11,530
Highway materials	32	2,360	18.8	5,460	43.4	4,760	37.8	12,580
Total	165	2,090	19.6	4,930	46.1	3,670	34.3	10,690
All types of load	3,675	2,420	13.2	8,380	45.7	7,520	41.1	18,320
Empty	1,971	2,230	25.0	3,860	43.2	2,830	31.8	8,920
Grand total	5,646	2,360	15.7	6,800	45.2	5,880	39.1	15,040

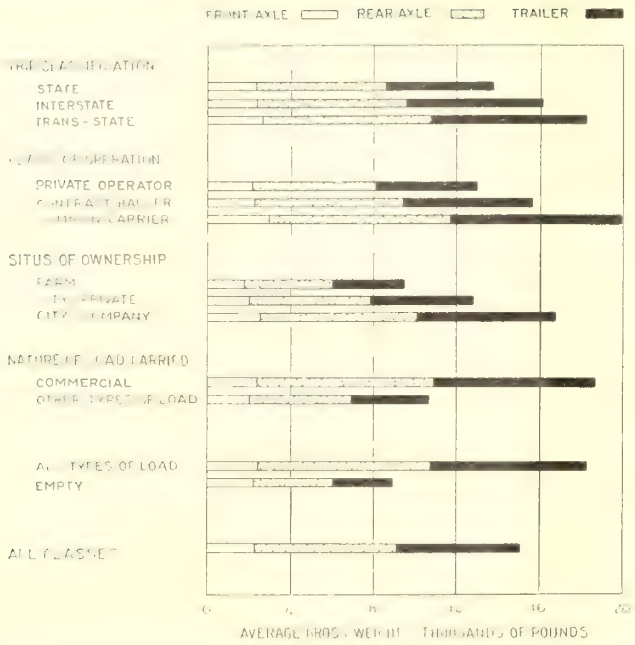

Figure 7.—Average Gross Axle and Trailer Loads of Truck-Trailer Combinations Recorded at 25 Stations by Various Classifications.

Except for five States adjacent to Arkansas—Louisiana, Missouri, Oklahoma, Tennessee, and Texas—the census grouping of States was used in figure 8. This grouping of States serves very well and makes possible comparisons with populations of these areas, should this be desired.

The small amount of traffic originating in Mississippi does not justify showing its traffic separately. The shortage of desirable crossings over the Mississippi River, a natural traffic barrier, accounts for the small volume of traffic from Mississippi, although there are suitable ferries at Helena and Lake Village. A bridge across the Mississippi River at Vicksburg also tends to divert traffic into Louisiana.

Most of the foreign passenger-car traffic originated in adjacent States. More than 75 percent of total foreign traffic had its origin in the six bordering States. The greatest amount of this traffic from a single geographical area had its origin in Missouri. An estimated total of 293,900 vehicles, or 19.7 percent of total was from that State.

Tennessee with 18.5 percent of the total, or 276,000 vehicles, was second in amount of foreign passenger-car traffic found upon Arkansas highways. Much of this movement of traffic from Tennessee was through Memphis. The Memphis bridge is the only one across the Mississippi River along the Arkansas border, and there was a considerable amount of across-the-border movement with a short trip mileage which was balanced by a large amount of long trips across the State.

Table 18.—*Average daily and estimated annual foreign passenger-car traffic at 51 stations near the Arkansas border*

Station number	Route	Foreign passenger cars	
		Daily	Annual [1]
1 NE	U S 67	152	55, 500
2 N	U S 63	293	106, 900
5	U S 61 and 70	2, 481	905, 600
17	U S 82	55	20, 100
18	U S 71	67	24, 500
19	U S 67	432	157, 700
20	U S 71 [2]	138	50, 400
22	U S 71 [2]	138	50, 400
23	Ark. 22	156	56, 900
24 SW	U S 64	253	92, 300
26 E	U S 62	88	32, 100
30 N	U S 61	864	315, 400
37 SE	Ark. 131	27	9, 900
61 N	U S 65	93	33, 900
62 N	Ark. 47	197	71, 900
63 N	U S 71	246	89, 800
63 W	Ark. 102	57	20, 800
64 W	Ark. 59	317	115, 700
65 W	U S 62	87	31, 800
75 SW	Ark. 45	25	9, 100
76 NE	Ark. 20	86	31, 400
77 E	Ark. 20	86	31, 400
97 S	Ark. 13	36	13, 100
100 SE	U S 65	102	37, 200
100 SW	Ark. 159	68	24, 800
115	U S 167	185	67, 500
121 NW	Ark. 32	32	11, 700
122 W	U S 70	74	27, 000
200 E	Ark. 90	44	16, 100
203 E	Ark. 25	236	86, 100
204 N	Ark. 77	99	36, 100
241	Ark. 115	23	8, 400
242 N	Ark. 93	7	2, 600
246 N	Ark. 5	23	8, 400
255 NE	Ark. 21	37	13, 500
259	Ark. 100	115	42, 000
270	Ark. 28	18	6, 600
275	U S 270	68	24, 800
276	Ark. 88	19	6, 900
278 W	Ark. 4	26	9, 500
290	U S 71	55	20, 100
291	Ark. 29	90	32, 800
292	Ark. 132	50	18, 200
294	U S 79	119	43, 400
295	Ark. 15	3	1, 100
298	Ark. 129	35	12, 800
299	Ark. 133	48	17, 500
300	U S 165	80	29, 200
303 SE	Ark. 142	9	3, 300
304 NE	U S 82	128	46, 700
307	Ark. 4	8	2, 900
Total		8, 175	2, 983, 800
Estimated number entering State		4, 088	1, 491, 900

[1] Annual traffic estimated by multiplying daily average by 365; individual station estimates of annual traffic adjusted to the nearest 100 vehicles.

[2] Station 20 was located near the Texas line; station 22 was located near Fort Smith.

Table 19.—*Origin of foreign passenger-car traffic in Arkansas*

Geographical area	Estimated annual traffic	Percentage distribution
Louisiana	152, 200	10. 2
Missouri	293, 900	19. 7
Oklahoma	188, 000	12. 6
Tennessee	276, 000	18. 5
Texas	208, 900	14. 0
New England States	6, 000	. 4
Middle Atlantic States	25, 400	1. 7
East North Central States	116, 400	7. 8
West North Central States except Missouri	86, 500	5. 8
South Atlantic States	32, 800	2. 2
East South Central States except Tennessee	49, 200	3. 3
Mountain States	16, 400	1. 1
Pacific States	37, 300	2. 5
Other [1]	3, 000	. 2
Total	1, 492, 000	100. 0

[1] Includes cars from Canada, Mexico, Panama, Puerto Rico, and Hawaii.

Texas, with a comparatively small amount of mileage bordering Arkansas, was the origin of 14 percent, or 208,900 vehicles, of the foreign passenger vehicles estimated to have entered Arkansas. Oklahoma with 12.6 percent and Louisiana with 10.2 percent accounted for the origin of 188,000 and 152,200 vehicles respectively, on Arkansas highways. The percentage of total and the number of vehicles originating in other areas are shown in table 19.

Excepting Tennessee and the East North Central States, the territory east of the Mississippi was not a source of much of the State's tourist traffic. The East North Central States contributed 7.8 percent, or

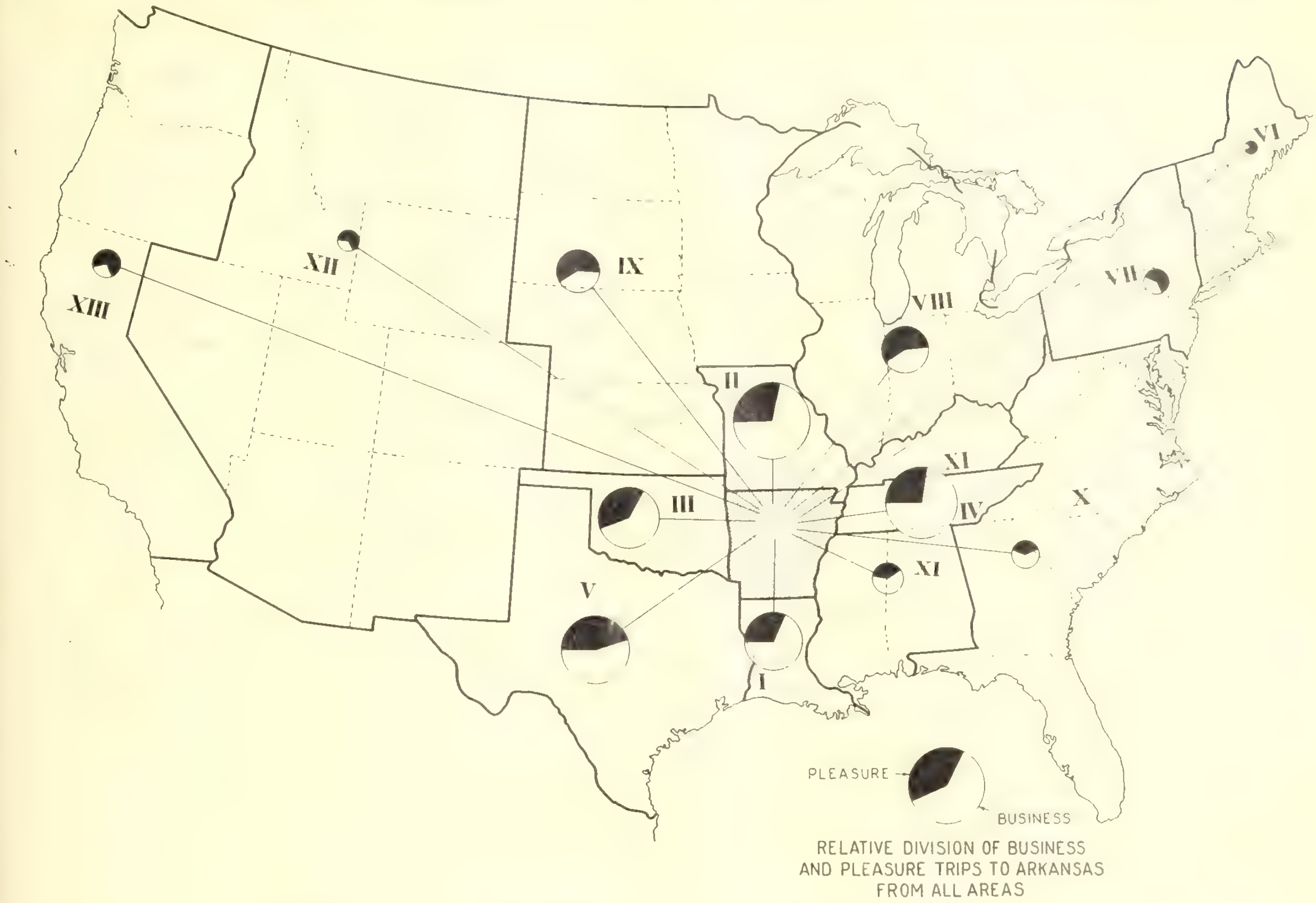

Figure 8.—Origin of Foreign Passenger-Car Traffic in Arkansas.

116,400 vehicles. The remaining territory east of the Mississippi River was responsible for less traffic than that of the East North Central States.

A little less than 6 percent of the foreign passenger cars that used Arkansas highways originated in the West North Central States (except Missouri), and about 59 percent of all cars from this area had their origin in Kansas.

Distance is not always the reason for a small amount of traffic from a particular State, as illustrated by the fact that California contributed 97 percent of the 37,300 foreign passenger cars that had their origin in the Pacific States.

More than twice as many cars had their origin in California as in the eight Mountain States. However, California has the second largest motor-vehicle registration of any State in the Union.

Slightly more than 0.2 percent of the foreign passenger cars had their origin outside of the continental United States, or were government cars which could not be distributed by areas of origin. These cars carried licenses from Canada, Mexico, Panama, Puerto Rico, and Hawaii.

HIGHWAY RESEARCH BOARD TO MEET IN DECEMBER

The Sixteenth Annual Meeting of the Highway Research Board of the National Research Council will be held in Washington, D. C., on November 18–20, 1936. A program of reports on research investigations is to be announced in the near future.

THE CONE METHOD FOR DETERMINING ABSORPTION BY SAND

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **D. O. WOOLF**, Associate Materials Engineer

THE NEED for an accurate method of determining the absorption of water by aggregates has been recognized ever since the design of concrete mixtures was approached on the basis of scientific principles. Only a portion of the water used in mixing concrete is needed for the complete hydration of the cement. The rest is necessary to lubricate the mix so that it may be placed uniformly and without undue difficulty. Some of this lubricating water may be absorbed by the aggregates, but the remainder, the so-called "free" water, dilutes and weakens the cement paste. Consideration of the strength of the resulting concrete must involve the amount of this diluting water, and a knowledge of the amount of water absorbed by the aggregates is necessary to determine the net water content available for the cement. The determination of the bulk specific gravity and from this the bulk volume and weight of the aggregates required for a given yield of concrete also necessitates a determination of the amount of absorbed water.

Methods of determining the water absorption of fine aggregate by means of a simple yet reasonably accurate test have been given considerable attention during the past several years and a number of methods have been devised. The majority of the procedures so far suggested are based on the observed behavior of sand grains in the presence of free moisture. Extensive study by the Bureau of Public Roads has disclosed that most of these methods are either liable to furnish inaccurate results or require such great care and are so sensitive to nominally uncontrolled variables that their use in routine testing is not warranted.

After reviewing briefly the various procedures that have been suggested, this report discusses the so-called "cone method" which has been developed by the writer after considerable study of this problem.

VISUAL INSPECTION AND KEROSENE METHODS REVIEWED

Probably the first method used for determining the condition usually known as "saturated and surface-dry", when the permeable pore spaces in the sand grains are filled with water without any moisture adhering to the surfaces of the grains, was by simple visual inspection. The procedure is simply to spread the sand out on a smooth surface and permit it to air dry, with or without artificial circulation. The sample is stirred frequently to insure uniform drying, and the end point is determined by noting when the sand appears to be surface-dry and free-flowing. The difference in the weight of sand in the saturated and surface-dry condition and the oven-dry weight is termed the absorption and is expressed as a percentage of the oven-dry weight.

This method has been considered capable of furnishing consistent results when used by a single operator but considerable doubt has been expressed as to the ability of different operators to check each other's results since the end point depends entirely on the operator's judgment. The development of a method with the end point based on measurable features was considered advisable.

In 1917, A. S. Rea presented a method of determining the so-called "apparent" specific gravity of nonhomogeneous fine aggregates.[1] This value for specific gravity, more properly called the "bulk" specific gravity, is defined as the ratio of the weight in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight of an equal volume of distilled water at the same temperature.[2] An accurate determination of this value requires that the permeable voids in the material under test be filled with water or some other substance, or that the voids be sealed against the entrance of water by some method before the volume of the displaced water is determined. Rea accomplished this by coating the sand grains with kerosene before determining the volume of the test sample.

It is apparent that if the bulk specific gravity can be determined by this kerosene method, the absorption of the material tested can also be determined. By means of a slight change, the method was later adapted to determine the absorption of fine aggregate.[3] In this method, duplicate 500-gram samples of oven-dried sand are placed in 500-milliliter volumetric flasks. A small amount of kerosene is added to one flask and the flask shaken to distribute the kerosene over all the sand grains. It is intended that the kerosene shall coat each sand grain to prevent absorption of water. The volume of a normal salt solution [4] required to fill the flask is then found. The excess kerosene floats on the top of the salt solution. A measured quantity of water is added to the second flask and the sand permitted to absorb water for a definite length of time. The volume of water required to fill the flask is then determined. The absorption is computed from the difference between the volume of water required to fill the flask containing the untreated sand and the volume of salt water required to fill the flask containing the kerosene-coated sand.

Although this method appears to be satisfactory in theory, a number of difficulties developed in actual practice. The most troublesome feature is found when sand containing clay or other fine particles is tested. Much of this fine material adheres to the globules of surplus kerosene and floats on the salt water. Shaking the flask or stirring the liquid seems to promote the formation of an emulsified liquid containing kerosene, salt water, clay or other fine particles, and air. A clean line of demarcation between the salt water and kerosene is seldom found, and in many cases only an approximate measurement of the amount of salt water required to fill the flask can be made.

For accurate determinations the test can be made only on thoroughly clean sand containing little if any fine particles. Reports from a number of different laboratories occasionally have shown negative values for tests made by this method. The writer is of the opinion that rolling and shaking the flask to remove surplus kerosene and entrapped air also tends to remove the kerosene film from the sand grains, allowing the sand to absorb water. This absorption, together with the flotation of fine particles by the kerosene emulsion, may cause the volume of salt water to exceed that of the fresh water, and a negative result is obtained.

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[1] Proceedings, American Society for Testing Materials, vol. 17, pt. II, p. 257.

[2] Standard Definition E 12-27, American Society for Testing Materials. Book of Standards, 1933, p. 1252.

[3] Proceedings, American Society for Testing Materials, vol. 20, pt. I, pp. 301-302 (1920).

[4] The higher density of the normal salt solution gives a better separation of the kerosene than would be obtained with the use of water.

OTHER METHODS DISCUSSED

In 1929 J. C. Pearson suggested[5] a new method of determining the absorption by sand. In this method a 200-gram sample of dry sand is placed in an Erlenmeyer flask and water added drop by drop until the finer grains adhere to the sides of the flask after thorough shaking. The weight of the flask and contents is then found; the sand is further dampened by several drops of water; and the sample is dried until the sand grains no longer adhere to the flask. The weight of flask and contents is again determined, and the average weight of the moistened sand is used in computing the absorption. This method has one major defect in that sufficient time for the complete absorption of the added water is not permitted. Consequently, the method may furnish results lower than the true absorption of the material under test.

In 1933, the American Society for Testing Materials adopted as tentative a method[6] for determining the absorption by sand. This method is based on Pearson's titration method. In the test, a sample of sand is thoroughly saturated with water, and then dried to a surface-dry condition as determined by visual examination. A 500-gram sample is taken from this saturated and surface-dry sand, and placed in a 1-quart glass jar. Water is added to the sample, drop by drop, with thorough shaking until the sand grains just tend to adhere to the sides of the jar. The weight of the sample is then found, and the sample dried to constant weight. The results of this method are in effect largely dependent on the accuracy of the operator's judgment that the sample is in a saturated and surface-dry condition. If drying of the sample is stopped exactly when the sand becomes surface-dry, the addition of one or two drops of water will indicate the end point; if the sample is dried past the surface-dry condition, the addition of one or two drops of water may indicate a false end point unless sufficient time is permitted for the absorption of the added water.

Chapman[7] has suggested that the saturated and surface-dry condition of sand can be determined from the change in color of the material when uniformly dried, and Graf and Johnson[8] have stated their belief that this condition can be determined by drying sand for several days over calcium chloride. It is doubted that the exact point of change in color can be precisely and repeatedly determined, or that desiccation will not remove some of the absorbed water.

In addition to the methods that have already been described, Myers[9] has presented a review and discussion of a number of methods based on gravimetric, displacement, dilution, colorimetric, and electrical-resistance principles. Many of these methods are primarily concerned with the determination of the free moisture in the aggregate, the accuracy of which depends upon placing the sand initially in a saturated and surface-dry condition by visual inspection.

Since none of the available methods were considered to combine the desirable characteristics of simplicity, ease of performance, and accuracy, an effort was made to devise a better method. Attention was first given to the possibility of mixing the sand with a material of known density and determining the density of the two substances combined. A number of oils and plastic materials were tried, but the method proved unsuccessful when sands containing finely divided particles were used. Recourse was then made to the method based on Rea's kerosene test for specific gravity, and tests conducted to find a substitute for kerosene that would furnish better results. None of the materials used gave any better results than kerosene, and further work along this line was abandoned.

DEVELOPMENT OF CONE METHOD DESCRIBED

An attempt was then made to use a very simple procedure. It was known that moist sand containing free water could be formed into shapes by light pressure and that dry sand could not. This characteristic has long been utilized in foundries in making molds for the casting of metal objects. If this feature could be used in a method of test it might prove a satisfactory means of determining the saturated and surface-dry condition of sand. Preliminary tests were made using a small, hollow, metal cone which was available. The sand was placed loosely in the cone and compacted by tamping it lightly with a metal rod having a flat face 1 inch in diameter. It was found that if the sand was dry the material would slump when the cone was removed, but if the sand contained free moisture the cone of sand would retain its form.

Further tests were made using right truncated cones having base angles of approximately 45°, 60°, 70°, and 80°. Samples of sand were immersed in water for 24 hours, drained, and dried to a free-flowing condition by a current of warm air. As the sand approached a surface-dry condition, tests were repeatedly made with each of the cones to determine the point at which the sand would slump when lightly tamped in the cone and the cone removed. The 45° and 60° cones did not prove practical. These angles were not sufficiently different from the natural angle of repose of the sand, and a definite slump was seldom obtained, especially when the sand contained clay.

The 80° cone gave a sharp point of slump, but a microscopic examination of the sand disclosed the presence of an appreciable amount of free water. The 70° cone also gave a definite point of slump. Microscopic examination of the sand at this point failed to show any evidence of free moisture, and it is believed that the use of the 70° cone determines the condition of the sand which is very close to that of the desired "saturated and surface-dry" material. The addition of a few drops of water to the test sample in the above condition caused the sand to retain its form after removal of the 70° cone, thus indicating the presence of free moisture.

There seems to be considerable divergence of opinion as to the reason for the cohesion developed by moist sand. P. G. Nutting[10] has stated that surface tension, vapor tension, atmospheric pressure, and internal (adsorption) pressure are the forces involved in causing the observed cohesion and resistance to deformation of moist sand. This cohesional force increases with the amount of water present up to a maximum and then falls to zero with complete wetting.

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[5] A Simple Titration Method for Determining the Absorption of Fine Aggregates by J. C. Pearson. Rock Products, vol. 32, no. 10, p. 64, May 11, 1929.

[6] Method C 95–33 T: Tentative Test for Absorption by Aggregates for Concrete (laboratory determinations).

[7] Discussion of Comparison of Methods of Determining Moisture in Sands. Proceedings, American Concrete Institute, vol. XXV, p. 261 (1929).

[8] Study of Methods for Determining Moisture in Sand, by S. H. Graf and R. H. Johnson. Proceedings, American Society for Testing Materials, vol. 30, pt. I, p. 578 (1930).

[9] Free Moisture and Absorption of Aggregates, by Bert Myers, in Report on Significance of Tests of Concrete and Concrete Aggregates, Committee C–9, American Society for Testing Materials, 1935.

Nutting further states that silica will adsorb a film of water from 50 to 100 molecules deep and that in coarse sand this water may amount to 1 milligram per gram of sand. However, this film of adsorbed water can be removed from sand grains only by extended desiccation or heating to a high temperature. The presence of this adsorbed water cannot be held the sole cause of the cohesion in damp sand since it is present in sand dried at 100° C. as well.

Other physicists do not agree with these views. It has been stated by one authority that absorbed water cannot be distinguished from adsorbed water, and that whether the water and the sand are physically or chemically combined, the cohesion of moist sand is caused only by the presence of water on the surface of the sand grains. Another has stated that adsorbed moisture is present in moist sand in very small amounts as a monomolecular film, but that this water behaves as free water and joins with any other moisture present in binding the sand grains together when the damp sand is compacted. That the monomolecular film of adsorbed water can by itself produce the cohesion of sand is doubted.

In general, the opinion seems to be that whatever the nature of the water in damp sand, a change in the cohesiveness of sand may be taken as an indication of a change in the condition of the sand from one in which free moisture exists on the surfaces of the grains to one in which no free moisture is present. Free moisture is here considered as that which causes the bulking of sand. Whether or not adsorbed moisture is present in the noncohesive sand seems to be a moot point. It seems to be generally agreed that the amount of this adsorbed water is so small, compared to the total "absorption" determined by this test, that it can have no practical effect on either the bulk specific gravity or the net water-cement ratio. The test is considered to be a logical if possibly an empirical method of determining a usable value by means of a readily standardized procedure.

PROCEDURE FOLLOWED IN MAKING CONE TEST OUTLINED

On the basis of the preliminary tests, a method for determining the absorption by sand was formulated as follows:

A 1,000-gram sample of sand shall be placed in a pan and covered with water for a period of at least 3 hours. The sample shall then be drained, placed in a large enamelware pan, and exposed to a gentle current of warm air. The sand shall be stirred frequently to insure uniform drying. When the sand appears to be approaching a surface-dry condition, trial determinations with the cone shall be started. A sheet metal cone with top and bottom diameters of 1½ and 3½ inches, respectively, and a height of 2⅞ inches, shall be placed in the pan and filled with sand which shall be lightly tamped 25 times with a 12-ounce metal rod having a flat face 1 inch in diameter. The cone shall then be lifted vertically. If the sand does not slump, free moisture is still present, and the drying shall be resumed. Trials with the cone shall be continued at frequent intervals until the sand slumps upon removal of the cone. This indicates that the sand has reached a surface-dry condition and the weight of the sample shall be determined. To insure that the sand has not been dried too much, a few drops of water shall be mixed with the sand, and the cone test repeated. Under these conditions, free water should be present, and the cone of sand should not slump. The weight of the sample shall again be determined, and the sample oven-dried to constant weight. The percentage of absorption shall be computed from the average of the two weights of the dampened sand and from the oven-dry weight.

Figure 1 shows the method of tamping the sand in the cone, a cone of a sand containing free moisture, and a slumped cone of the same sand after the material had reached a surface-dry condition.

In making the cone test, the following features should be observed:

1. The sample should be stirred frequently to obtain uniform drying.
2. The first trial for slump should find the sample with free moisture present.
3. Successive trials should be made at frequent intervals. The practice in the laboratory of the Bureau is to dry the sample under artificial circulation of air. As the sand approaches the surface-dry condition, drying is continued for definite lengths of time and trial determinations made at more and more frequent intervals. Under closely controlled conditions, ½-minute drying periods are used immediately prior to determination of the point of slump.
4. The metal cone should be lifted vertically. If it is not carefully removed, the sand cone may be struck and caused to slump prematurely.

One criticism of the cone method which has been made is that the test result obtained is influenced by the surface area of the sand grains. To investigate this, a series of tests was made with the cone method on several different gradings of five different sands. In preparing each set of test samples, a large amount of sand was separated into different sizes by sieving, and a series of samples definitely graded from coarse to fine was obtained. If the cone method results were influenced by the surface area of the material, it would be expected that the test value would be increased with change in the grading from coarse to fine. As shown in table 1, however, the percentage of absorption decreased slightly with increase in fineness for each sand. These results indicate that the larger grains have a somewhat higher ratio of volume of permeable voids to volume of grain than is found in finer sand. The greater absorption of the larger grains may explain the usual results of the accelerated soundness test for sand in which the coarser material shows the greater loss.

To shorten the time required for drying the sample, a warm air blower was devised. An 8-inch electric fan was mounted so that the blades rotated in a horizontal plane 24 inches above the table surface, and a sheet-metal tube 12 inches long was fastened to the wire guard around the fan blades. A series of electric resistance coils, drawing 1,250 watts, was mounted in the tube, and a three-speed rheostat was placed in the field circuit of the fan motor. The test sample was placed beneath the opening in the tube and a gently

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[10] Some Mechanical Properties of Moist Granular Solids, by P. G. Nutting. Journal, Washington Academy of Sciences, vol. 17, no. 8, p. 185, Apr. 19, 1927.

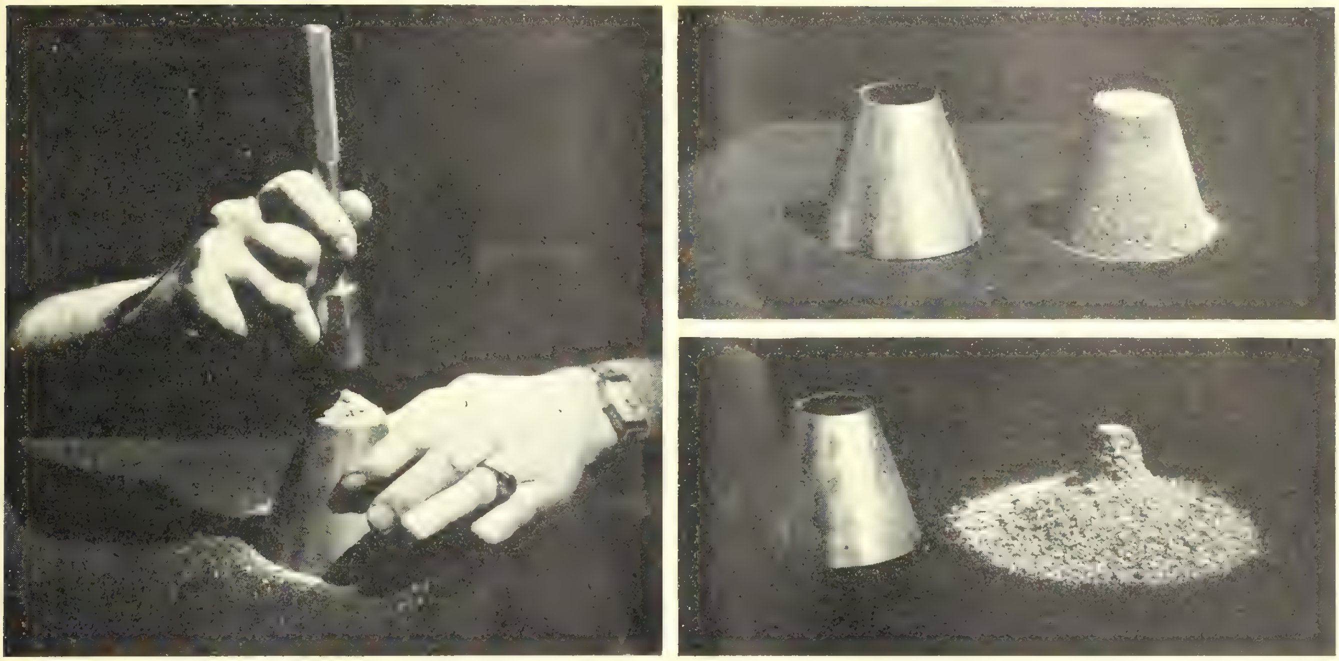

FIGURE 1.—STEPS IN PERFORMING THE CONE TEST ON SAND. LEFT; TAMPING MOIST SAND IN THE CONE. UPPER RIGHT; THIS SAND CONE RETAINED ITS SHAPE INDICATING THE PRESENCE OF FREE MOISTURE. LOWER RIGHT; THIS SAND CONE SLUMPED, INDICATING THAT THE MATERIAL HAD REACHED A SURFACE-DRY CONDITION.

moving current of warm air blown on it. With this apparatus the drying of a sample could be accomplished in about 1 hour.

TABLE 1.—*Comparison between grading of test samples and percentages of absorption*

VARIOUS GRADINGS USED[1]

Item	Grading									
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sieve no. 4	2	0	0	1	0	1	0	0	0	0
Sieve no. 8	24	25	14	12	8	8	0	0	0	0
Sieve no. 16	46	47	30	27	17	17	4	4	0	0
Sieve no. 30	80	80	73	70	60	60	45	45	40	40
Sieve no. 50	95	95	93	90	85	85	75	75	70	70
Sieve no. 100	100	100	100	97	100	95	100	93	100	90
Fineness modulus	3.47	3.47	3.10	2.97	2.70	2.66	2.24	2.17	2.10	2.00

ABSORPTION BY VARIOUS GRADINGS OF DIFFERENT SANDS

	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
River sand no. 1	1.19			1.19		1.17		1.15		1.14
River sand no. 2[2]		2.1	1.8		1.8		1.7		1.6	
Pit sand no. 1		2.1			1.9				1.7	
Pit sand no. 2		1.9			1.8				1.5	
Pit sand no. 3		.4			.4				.3	

[1] Values are percentages retained on the various sieves.
[2] Each value is the average of two tests.

COOPERATIVE ABSORPTION TESTS ON SANDS PERFORMED BY SEVERAL LABORATORIES

Following the establishment of a presumably satisfactory method of test, a large number of tests was made by different operators in the laboratory. Typical values for absorption are given in table 2. The results of these tests were considered so promising that it was decided to submit this method to a number of other laboratories for their criticisms. Several laboratories were accordingly invited to cooperate with the Bureau in an investigation of methods of determining absorp-

TABLE 2.—*Results of cone absorption tests on various sands*

Sample number	Location	Fineness modulus	Absorption	Mineralogical composition[1]
			Percent	
34810	Potomac River, D. C	3.00	1.4	Q, S, C.
34897	do	2.83	1.2	Q, S, C.
34900	do	2.85	1.2	Q, C, S
34901	do	2.84	1.2	Q, C, S.
34902	do	2.81	1.2	Q, C, S.
34904	do	2.96	1.5	Q, C, S.
34919	do	2.87	1.2	Q, C, S.
34921	do	2.76	1.5	Q, C, S.
34922	do	2.86	1.3	Q, C, S.
34927	do	2.87	1.4	Q, S, C.
	Ottawa, Ill	3.00	.05	Q.
	Bowie, Md		.8	Q, C.
34845	Monroe, Mich	3.00	3.7	Limestone sand.
34618	Albany, N. Y	2.82	2.4	S, Sl, Sh, Q, L.
34804	do	2.81	2.4	S, Sh, Sl, Q, L.
34621	Alexander, N. Y	3.27	1.8	L, Q, Sh, S.
34805	Alfred Station, N. Y	2.53	1.8	S, L, Q, C.
34806	Attica, N. Y	2.60	2.1	S, Sl, Sh, Q, C, L.
34807	Boonville, N. Y	2.88	.6	Q, F, G, C, L.
34623	Clarence, N. Y	2.71	1.7	L, S, Q, Sh, G.
34808	Port Jefferson, N. Y	2.64	.4	Q.
34809	Springville, N. Y	2.85	2.2	S, Sh, Sl, L, Q, C.
34620	Near Utica, N. Y	2.87	2.7	L, Sh, Q, S.
34903	Comanche County, Okla	3.01	1.4	Q, C, F, G.
34826	Silica, Ohio	3.08	1.9	Limestone sand.
34977	do	2.97	1.7	Do.
34861	———, R. I		.6	
34862	do		1.7	
34863	do		.9	
32364	Pon Pon, S. C	2.95	.2	Q.
34942	Elizabethton, Tenn	2.61	1.3	Q, S.
34945	Knoxville, Tenn	2.62	1.3	Q, S, C, M.
34943	Nashville, Tenn	2.55	2.5	Q, S, C.
34944	do	2.67	2.6	Q, C, S.
34940	Siam, Tenn	2.60	1.4	Q, S, G.
34941	do	2.79	1.4	Q, S, G.
34946	Strawberry Plains, Tenn	2.89	.8	Limestone sand.
34908	Fredericksburg, Va	2.97	.9	Q, Sc, Gn.
34844	Martinsburg, W. Va	3.04	.7	Limestone sand.

[1] Explanation of symbols used:

C=Chert
F=Feldspar
G=Granite
Gn=Gneiss
L=Limestone
M=Mica
Q=Quartz
S=Sandstone
Sc=Schist
Sh=Shale
Sl=Slate

tion. The following laboratories cooperated in the investigation:

Duquesne Slag Products Co.
Indiana State Highway Commission.
Iowa State Highway Commission.
Michigan State Highway Department.
National Crushed Stone Association.
National Sand and Gravel Association.
Pennsylvania Department of Highways.
Portland Cement Association.
Rhode Island State Board of Public Roads.
Virginia Department of Highways.
West Virginia State Road Commission.
Bureau of Public Roads.

In this series of cooperative tests, each laboratory was requested to make five tests by each of four different methods on each of six different samples of fine aggregate. The methods are included in those previously described, and are designated in the tables and figures that follow by the following numbers:

1. Kerosene method.
2. A. S. T. M. Tentative Method C 95-33 T.
3. Cone method.
4. Visual inspection method.

The samples of fine aggregate used in these tests were obtained by the Bureau, mixed thoroughly, and suitable portions of each sent to the cooperating laboratories. Effort was made to obtain sands having a considerable range in absorption, and the samples selected were as shown in table 3.

TABLE 3.—*Sands used in cooperative tests*

Sand	Source	Mineralogical composition
1	Massachusetts	Quartz, granite, diorite, rhyolite, feldspar, sandstone.
2	New York	Limestone, sandstone, quartz, chert.
3	South Carolina	Quartz.
4	Kansas	Quartz, feldspar, chert.
5	Rhode Island	Quartz, feldspar, granite, slate.
6	Ohio	Limestone (crushed stone sand).

The results of this series of cooperative tests are shown in tables 4, 5, and 6, and figures 2, 3, and 4. Tests were made in one laboratory by three different operators, and the results for this laboratory are shown in table 4. The individual results for each of the other laboratories are shown in table 5 and the average values for each laboratory, sand, and method are grouped together to permit ready comparison in table 6.

Figure 2 gives the average value obtained by all laboratories for each sand by each method of test. With the exception of sand number 3, the values obtained by the use of the kerosene method are considerably lower than those for the other test methods. This may have been caused by the removal of a portion of the kerosene from the sand grains when the flask was shaken to free the excess kerosene, or it may have been caused by the retention of a portion of the sample by the floating kerosene. In either case the result would be the same in that an excessive quantity of salt water would be added to the flask. This would of course decrease the difference between the volumes of fresh and salt water and would furnish a low value for the percentage of absorption. The average values for the cone method were found to be slightly higher than those for the tentative A. S. T. M. or visual inspection methods, but the difference in results was marked only in the case of the stone sand sample, number 6.

TABLE 4.—*Individual test results of percentage of absorption for laboratory no. 1*

Sand	Test	Method 1, operator		Method 2, operator			Method 3, operator			Method 4, operator		
		1	2	1	2	3	1	2	3	1	2	3
		Per-cent	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
1	1	0.1	0.3	0.6	0.6	0.8	0.8	0.8	0.8	0.6	0.6	0.8
	2	.2	.3	.7	.7	.6	.7	.8	.8	.7	.7	.7
	3	.1	.1	.8	.8	.7	.8	.8	.8	.7	.8	.7
	4	.0	.3	.8	.8	.8	.9	.8	.9	.8	.8	.7
	5	.0	.3	.9	.8	.7	.7	.7	.8	.9	.8	.7
	Average	.1	.3	.8	.7	.7	.8	.8	.8	.7	.7	.7
2	1	.5	.8	1.5	1.4	1.8	1.6	1.6	1.9	1.5	1.5	1.8
	2	.4	.5	1.7	1.6	1.9	1.7	1.7	1.8	1.7	1.5	1.9
	3	.4	.6	1.6	1.5	1.7	1.7	1.8	1.8	1.6	1.5	1.8
	4	.3	.6	1.7	1.7	1.8	1.7	1.8	2.0	1.7	1.6	1.8
	5	.1	.8	1.4	1.6	2.0	1.7	1.7	2.0	1.7	1.6	2.0
	Average	.3	.7	1.6	1.6	1.8	1.7	1.7	1.9	1.6	1.5	1.9
3	1	.2	.1	.2	.1	.2	.2	.2	.2	.2	.1	.2
	2	.2	.2	.2	.2	.2	.3	.2	.3	.2	.2	.2
	3	.2	.1	.2	.1	.2	.2	.2	.3	.2	.1	.2
	4	.2	.2	.2	.1	.2	.3	.3	.2	.2	.1	.2
	5	.3	.1	.3	.1	.1	.3	.2	.2	.2	.1	.2
	Average	.2	.1	.2	.1	.2	.3	.2	.2	.2	.1	.2
4	1	.2	.1	.7	.7	.8	.7	.7	.7	.7	.7	.7
	2	.3	.2	.7	.5	.5	.7	.7	.7	.7	.5	.8
	3	.1	.0	.7	.7	.6	.7	.6	.7	.7	.6	.7
	4	.0	.0	.7	.5	.6	.6	.6	.7	.7	.6	.7
	5	.1	.0	.6	.5	.7	.6	.7	.7	.6	.6	.7
	Average	.1	.1	.7	.6	.6	.7	.7	.7	.7	.6	.7
5	1	.0	.3	.6	.7	.8	.7	.7	.8	.6	.6	.8
	2	.0	.2	.7	.6	.6	.6	.7	.7	.7	.6	.6
	3	.0	.3	.7	.7	.7	.7	.7	.7	.7	.6	.7
	4	.0	.1	.7	.8	.7	.7	.7	.7	.7	.7	1.0
	5	.0	.3	.6	.6	.7	.7	.8	.6	.6	.5	.7
	Average	.0	.2	.7	.7	.7	.7	.7	.7	.7	.6	.8
6	1	.6	.8	1.5	1.3	-----	1.8	1.9	-----	1.3	1.3	-----
	2	.7	.7	1.6	1.2	-----	1.6	1.6	-----	1.8	1.1	-----
	3	.0	.8	1.5	1.2	-----	1.5	1.5	-----	1.4	1.4	-----
	4	.4	.4	1.2	1.6	-----	1.9	2.0	-----	1.1	1.4	-----
	5	.0	.7	1.6	2.1	-----	1.7	1.3	-----	1.7	1.7	-----
	Average	.3	.7	1.5	1.5	-----	1.7	1.7	-----	1.5	1.4	-----

TABLE 5.—*Individual test results on percentage of absorption*

USING METHOD 1

Sand	Test	Laboratory no.										
		2	3	4	5	6	7	8	9	10	11	12
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	1	0.25	1.20	0.38	0.52	0.28	0.80	0.33	0.70	0.50	-----	0.15
	2	.70	1.10	.79	.80	.23	-----	.40	.70	.43	-----	Tr.
	3	1.02	-----	.55	.7	.25	-----	.37	.73	.38	-----	.21
	4	.55	.85	.82	.5	.28	-----	.25	.65	.35	-----	-----
	5	.47	.55	.24	.4	.25	-----	.32	.65	.38	-----	-----
2	1	1.97	.80	.77	.95	.50	-----	.75	1.02	.98	-----	.47
	2	.81	.65	.55	.67	.48	-----	.60	1.15	.93	-----	.53
	3	.60	.80	.38	.9	.50	-----	.62	.99	.88	-----	.75
	4	1.33	.10	.58	.7	.58	-----	.82	1.09	.95	-----	-----
	5	.60	.30	.62	1.0	.50	-----	.70	1.06	.85	-----	-----
3	1	.55	1.00	.12	.42	.25	-----	.17	.28	.40	-----	.04
	2	.53	-----	.15	.42	.20	-----	.27	.30	.23	-----	.13
	3	.47	.90	.20	.4	.28	-----	.17	.30	.20	-----	.14
	4	.75	.80	.21	.8	.28	-----	.15	.31	.15	-----	-----
	5	.47	.50	.22	.5	.35	-----	.15	.28	.25	-----	-----
4	1	.50	1.00	.00	.00	.05	-----	.22	.40	.50	-----	.14
	2	.63	.65	.00	.42	.10	-----	.25	.43	.48	-----	(1)
	3	.32	.90	.05	.00	.03	-----	.07	.40	.53	-----	(1)
	4	.20	.50	.1	.5	.10	-----	.05	.43	.60	-----	-----
	5	.35	-----	-----	.0	.08	-----	.05	.39	.48	-----	-----
5	1	.37	1.10	.23	.50	.43	-----	.30	.45	.65	-----	(1)
	2	.35	1.35	.20	.75	.38	-----	.22	.43	.63	-----	.07
	3	.32	.85	.12	.5	.33	-----	.20	.40	.55	-----	.12
	4	.25	1.15	.26	.6	.38	-----	.22	.41	.68	-----	-----
	5	.25	1.05	.12	.7	.38	-----	.22	.40	.60	-----	-----
6	1	1.49	.25	.77	.52	.25	-----	1.92	1.16	1.13	-----	-----
	2	1.46	.15	.75	.95	.38	-----	1.71	1.13	1.10	-----	.51
	3	1.68	.75	.85	.5	.58	-----	1.65	1.13	.93	-----	.74
	4	1.26	.35	.75	.7	.63	-----	2.08	1.10	1.05	-----	-----
	5	1.50	.45	.45	.9	.50	-----	1.88	1.00	.83	-----	-----

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[1] Negative value obtained.

TABLE 5.—*Individual test results on percentage of absorption*—Continued

USING METHOD 2

Sand	Test	Laboratory no. 2	3	4	5	6	7	8	9	10	11	12
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	1	0.77	0.91	0.60	0.3	0.64	0.72	0.91	0.54	0.40	0.76	0.45
	2	1.10	.87	.58	.5	.66	.87	.86	.49	.23	.79	.40
	3	.77	1.02	.68	.3	.69	.68	1.02	.46	.22	.83	.43
	4	.67	1.00	.66	.4	.90	.55	.96	.46	.20	.75	-----
	5	.86	.88	.68	.5	.78	.64	.90	.54	.17	.80	-----
2	1	.87	1.69	1.48	.5	1.95	1.86	1.56	1.11	1.31	-----	1.21
	2	1.36	1.61	1.12	.6	2.41	1.90	1.50	1.13	1.24	-----	1.22
	3	1.18	1.55	1.42	.7	2.12	1.84	1.46	1.09	1.40	-----	1.18
	4	.99	1.61	1.32	.5	1.66	1.87	1.56	1.11	1.37	-----	-----
	5	.90	1.64	1.40	.4	2.25	1.74	1.56	1.19	1.20	-----	-----
3	1	.23	.25	.16	.6	.10	.10	.15	.12	.16	-----	.10
	2	.91	.27	.28	.6	.12	.10	.30	.08	.18	-----	.15
	3	.85	.24	.34	.3	.08	.10	.30	.12	.15	-----	.16
	4	.73	.22	.40	.3	.01	.10	.15	.17	.16	-----	-----
	5	.61	.27	.22	.3	.08	.10	.15	.10	.16	-----	-----
4	1	.46	.90	.62	.3	.61	.61	.45	.47	.61	-----	.54
	2	1.02	.83	.42	.2	.74	.56	.50	.44	.57	-----	.58
	3	.48	.69	.74	.5	.76	.64	.40	.40	.55	-----	.46
	4	.81	.55	.68	.5	.56	.57	.50	.42	.59	-----	-----
	5	.67	.59	.80	.5	.60	.53	.50	.40	.54	-----	-----
5	1	.48	.74	.68	.6	.89	.50	.60	.42	.49	-----	.44
	2	.87	.76	.48	.6	.84	.51	.50	.45	.53	-----	.46
	3	1.10	.62	.70	.4	.85	.57	.50	.38	.42	-----	.44
	4	.91	.65	.38	.3	.93	.56	.60	.38	.51	-----	-----
	5	.57	.69	.52	.4	.79	.56	.50	.38	.47	-----	-----
6	1	1.29	1.41	1.09	.4	.98	1.50	1.47	.95	1.43	-----	.89
	2	1.31	1.55	1.21	.4	.75	1.35	1.26	1.07	1.27	-----	.75
	3	1.59	1.41	1.10	.4	.71	1.43	1.27	1.03	1.51	-----	.81
	4	1.35	1.38	1.04	.2	1.08	1.14	1.37	.96	1.41	-----	-----
	5	1.30	1.52	1.17	.2	.90	1.19	1.27	1.11	1.35	-----	-----

USING METHOD 3

Sand	Test	Laboratory no. 2	3	4	5	6	7	8	9	10	11	12
1	1	1.38	0.92	0.77	0.6	0.90	0.72	0.84	0.78	0.45	0.78	0.72
	2	1.47	.70	.82	.7	.86	.77	.85	.79	.59	.76	.75
	3	1.90	.72	.79	.6	.90	.76	.92	.75	.58	.75	.76
	4	.59	.66	.76	1.3	.93	.80	.91	.81	.62	.78	-----
	5	.61	.81	.83	1.0	.86	.80	.88	.79	.54	.79	-----
2	1	2.05	1.62	1.64	1.3	1.60	1.57	1.72	1.54	1.10	1.58	1.43
	2	1.75	1.63	1.46	.8	1.67	1.52	1.62	1.57	1.05	1.52	1.34
	3	2.08	1.49	1.47	.8	1.57	1.66	1.59	1.55	1.27	1.56	1.47
	4	2.46	1.49	1.62	1.5	1.35	1.70	1.69	1.57	1.24	1.49	-----
	5	2.43	1.56	1.67	1.5	1.74	1.57	1.62	1.61	1.30	1.72	-----
3	1	.98	.27	.24	.3	.24	.25	.25	.18	.10	-----	.17
	2	.58	.19	.19	.5	.15	.22	.22	.22	.14	-----	.15
	3	.66	.25	.22	.5	.21	.25	.25	.23	.14	-----	.21
	4	.65	.24	.17	.6	.19	.18	.22	.18	.14	-----	-----
	5	.65	.29	.17	.6	.19	.20	.27	.22	.12	-----	-----
4	1	.69	.53	.57	.4	.59	.78	.72	.59	.58	-----	.57
	2	1.31	.62	.58	.9	.53	.76	.72	.60	.50	-----	.51
	3	.16	.44	.62	.5	.45	.70	.67	.61	.55	-----	.56
	4	.36	.62	.59	.7	.48	.76	.70	.62	.57	-----	-----
	5	.60	.59	.50	.8	.52	.66	.72	.63	.58	-----	-----
5	1	.27	.71	.77	.8	.63	.55	.80	.69	.57	-----	.75
	2	.15	.66	.75	.8	.63	.62	.75	.73	.59	-----	.77
	3	.21	.65	.66	.6	.70	.68	.75	.68	.58	-----	.80
	4	.39	.71	.66	1.1	.65	.61	.80	.70	.57	-----	-----
	5	.47	.71	.77	1.3	.60	.65	.80	.72	.55	-----	-----
6	1	1.68	1.60	1.99	1.3	1.27	1.76	2.02	1.54	1.25	-----	1.11
	2	2.20	1.75	1.68	1.1	1.42	1.57	2.04	1.98	1.16	-----	1.09
	3	2.30	1.60	1.80	1.0	1.45	1.77	1.84	1.55	1.18	-----	1.21
	4	2.25	1.75	1.55	1.8	1.22	1.97	1.94	1.41	1.10	-----	-----
	5	2.20	1.62	1.62	1.4	1.18	2.00	2.06	1.61	1.12	-----	-----

USING METHOD 4

Sand	Test	Laboratory no. 2	3	4	5	6	7	8	9	10	11	12
1	1	0.98	0.71	0.61	1.2	0.65	0.69	0.40	0.70	0.39	0.79	0.32
	2	.93	.76	.65	1.1	.66	.75	.40	.76	.37	.77	.40
	3	1.43	.89	.58	.6	.67	.60	.40	.73	.47	.81	.38
	4	.81	.77	.68	.8	.64	.56	.29	.71	.36	.73	-----
	5	.87	.68	.64	.6	.67	.30	.50	.71	.51	.74	-----
	6	-----	-----	-----	-----	-----	.56	-----	-----	-----	-----	-----
	7	-----	-----	-----	-----	-----	.50	-----	-----	-----	-----	-----
	8	-----	-----	-----	-----	-----	.58	-----	-----	-----	-----	-----
	9	-----	-----	-----	-----	-----	.50	-----	-----	-----	-----	-----
2	1	1.39	1.61	1.32	1.9	1.31	1.30	1.41	1.40	1.28	-----	1.10
	2	1.64	1.52	1.50	2.0	1.19	1.58	1.25	1.37	1.32	-----	.99
	3	1.79	1.56	1.19	.7	1.14	1.52	1.28	1.33	1.35	-----	1.05
	4	1.91	1.51	1.38	.9	1.26	1.53	1.45	1.42	1.28	-----	-----
	5	1.24	1.57	1.39	.6	1.29	-----	1.45	1.36	1.32	-----	-----
4	1	.50	.20	.22	1.1	.09	.18	.10	.22	.13	-----	.13
	2	.48	.23	.20	1.2	.08	.17	.13	.24	.10	-----	.10
	3	.63	.22	.35	.6	.18	.23	.15	.21	.11	-----	.14
	4	.26	.22	.20	.5	.15	.19	.13	.22	.14	-----	-----
	5	.25	.31	.16	.5	.12	.16	.13	.23	.11	-----	-----

TABLE 5.—*Individual test results on percentage of absorption*—Continued

USING METHOD 4—Continued

Sand	Test	Laboratory no. 2	3	4	5	6	7	8	9	10	11	12
		Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct*
4	1	0.83	0.56	0.52	1.0	0.51	0.60	0.32	0.70	0.48	-----	0.42
	2	.71	.52	.66	.9	.60	.49	.35	.67	.54	-----	.36
	3	.78	.56	.56	.4	.50	.53	.38	.67	.52	-----	.36
	4	.86	.43	.50	.4	.50	.55	.45	.65	.40	-----	-----
	5	1.02	.56	.58	.5	.51	.49	.43	.60	.50	-----	-----
5	1	1.59	.54	.57	1.3	.44	.66	.55	.75	.41	-----	.33
	2	1.07	.59	.72	1.2	.46	.58	.60	.69	.39	-----	.40
	3	1.77	.59	.50	.8	.51	.61	.58	.75	.34	-----	.40
	4	1.84	.58	.53	.5	.49	.65	.50	.77	.34	-----	-----
	5	1.43	.59	.59	.9	.48	.65	.45	.71	.40	-----	-----
6	1	1.33	1.42	1.21	1.3	1.41	1.64	1.59	1.07	1.22	-----	.50
	2	1.43	1.35	.99	1.3	1.74	1.61	1.54	1.12	1.16	-----	.57
	3	1.70	1.45	1.25	.7	1.59	1.20	1.61	1.16	1.16	-----	.59
	4	1.45	1.33	1.17	.9	1.12	1.74	1.63	1.01	1.11	-----	-----
	5	1.45	1.40	1.12	.6	1.36	1.61	1.48	-----	1.15	-----	-----

TABLE 6.—*Average values for percentage of absorption of various sands, determined by various methods in various laboratories*

Sand	Method	Laboratory 1	2	3	4	5	6	7	8	9	10	11	12	Average
		Pct	*Pct.*	*Pct*	*Pct*	*Pct*	*Pct*	*Pct*	*Pct.*	*Pct*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
1	1	0.2	0.60	0.93	0.6	0.6	0.26	0.80	0.33	0.67	0.41	0.34	0.18	0.49
	2	.7	.83	.94	.6	.4	.73	.69	.93	.50	.24	.79	.43	.65
	3	.8	1.11	.76	.8	.8	.89	.77	.88	.78	.55	.77	.74	.80
	4	.7	1.00	.76	.6	.9	.66	.56	.40	.72	.42	.77	.37	.65
2	1	.5	1.06	.53	.6	.9	.51		.70	1.06	.92	.66	.58	.73
	2	1.7	1.06	1.62	1.4	.5	2.08	1.84	1.53	1.13	1.30	1.62	1.20	1.42
	3	1.8	2.15	1.56	1.6	1.2	1.59	1.60	1.65	1.57	1.19	1.58	1.41	1.57
	4	1.7	1.59	1.55	1.4	1.2	1.24	1.48	1.37	1.38	1.31	1.61	1.05	1.41
3	1	.2	.55	.80	.2	.5	.27		.18	.29	.25	.42	.10	.34
	2	.2	.67	.25	.3	.4	.08	.10	.21	.12	.16	.21	.14	.24
	3	.2	.70	.25	.2	.5	.20	.22	.24	.21	.13	.24	.18	.27
	4	.2	.42	.24	.2	.8	.12	.19	.13	.22	.12	.23	.12	.25
4	1	.1	.40	.76	.0	.2	.07		.13	.41	.52	.36	.14	.28
	2	.6	.69	.71	.6	.4	.65	.58	.47	.43	.57	.61	.53	.57
	3	.7	.62	.56	.6	.7	.51	.73	.71	.61	.56	.65	.55	.62
	4	.7	.84	.53	.6	.6	.52	.53	.39	.66	.49	.63	.38	.57
5	1	.1	.31	1.10	.2	.6	.38		.23	.42	.62	.44	.10	.41
	2	.7	.79	.69	.6	.5	.86	.54	.54	.40	.48	.73	.45	.61
	3	.7	.30	.69	.7	.9	.64	.62	.78	.70	.57	.79	.77	.68
	4	.7	1.54	.58	.6	.9	.48	.63	.54	.73	.38	.72	.38	.68
6	1	.5	1.48	.39	.7	.7	.47		1.85	1.10	1.01	.79	.62	.87
	2	1.5	1.37	1.45	1.1	.3	.88	1.32	1.33	1.02	1.40	1.67	.82	1.18
	3	1.7	2.11	1.66	1.7	1.3	1.31	1.82	1.98	1.63	1.16	1.42	1.14	1.58
	4	1.4	1.47	1.39	1.2	1.0	1.44	1.56	1.57	1.09	1.16	1.48	.55	1.28

CONE METHOD FOUND TO GIVE MOST CONSISTENT RESULTS

It is possible that the extreme angularity of the stone sand was the determining factor in causing the higher value in the cone test than in the A.S.T.M. or visual inspection tests. It is also possible that there may have been some cementing of the particles by the dust present in the material. On the other hand, the dust present in the stone sand may have had such an affinity for moisture that the A.S.T.M. and visual inspection tests continued to show water present although the larger portion of the sample was only partially saturated. This would account for the lower values obtained by the use of these two methods.

In figure 3, the percentage deviation of the average result for each laboratory from the average for all laboratories is given for each method. Each value is an average for all six sands, except that the reported value for laboratory 7 for the kerosene method (no. 1) is for one sand only. These values show that the cone method (no. 3) furnished test results that were most nearly duplicated by different laboratories. Using

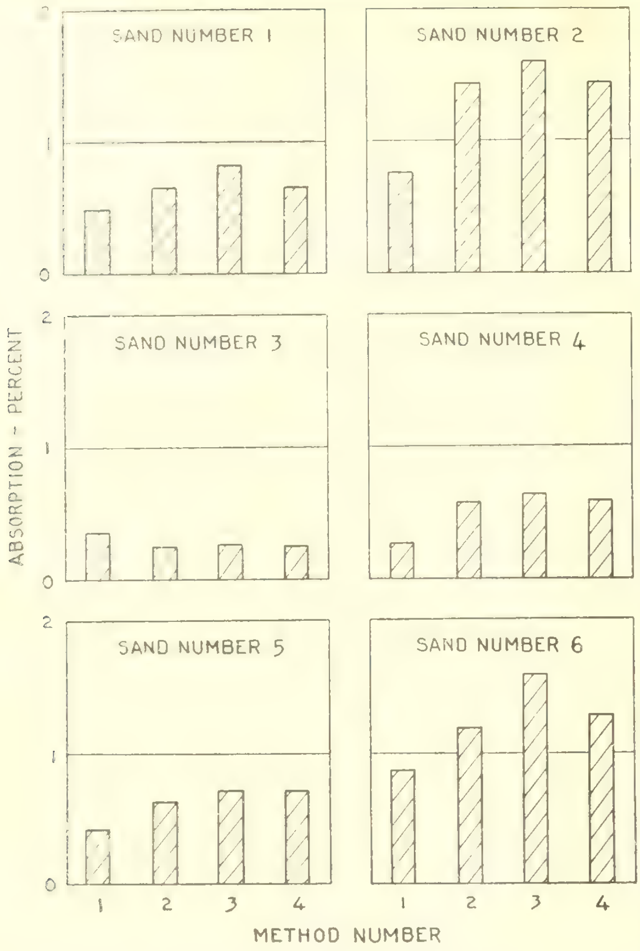

FIGURE 2.—AVERAGE RESULTS OBTAINED BY ALL LABORATORIES WITH EACH METHOD FOR DETERMINING THE ABSORPTION BY SAND.

the cone method, only 1 laboratory (no. 2) showed a marked deviation from the average, and 8 of the 12 laboratories had deviations of 15 percent or less. The average deviation for all laboratories was 17 percent.

The visual inspection method appears to be the second most accurate. Three laboratories showed wide variations from the average but six had variations of 15 percent or less. The average deviation was 24 percent. The tentative A. S. T. M. method (no. 2) gave about the same average variation (26 percent) as the visual inspection method, but only two laboratories had deviations of 15 percent or less, while seven laboratories showed deviations of 16 to 30 percent. The kerosene method was the least accurate of those under consideration. Only two laboratories showed deviations of less than 30 percent and results deviating from the average by over 50 percent were found in four laboratories. The average deviation for the kerosene method was 47 percent.

The deviations within a given laboratory as shown in figure 4 indicate that concordant results are usually obtained by the use of the tentative A. S. T. M., cone, and visual inspection methods. In most cases the kerosene method failed to furnish results agreeing with each other to a satisfactory degree.

In considering the entire series of tests, the cone method appears to be the most satisfactory means of determining the absorption by sand. It furnishes more concordant results between different laboratories than any of the other methods under consideration, and permits an operator to check his own work with an average variation of less than 10 percent. The average values for percentage of absorption found by this method agree very closely with those of the tentative A. S. T. M. and visual inspection methods. The tentative A. S. T. M. and visual inspection methods give very good agreement between the results of tests made by a single operator and fair agreement between the results of different laboratories. The kerosene method is found to give low and very erratic results and further use of this method is not recommended.

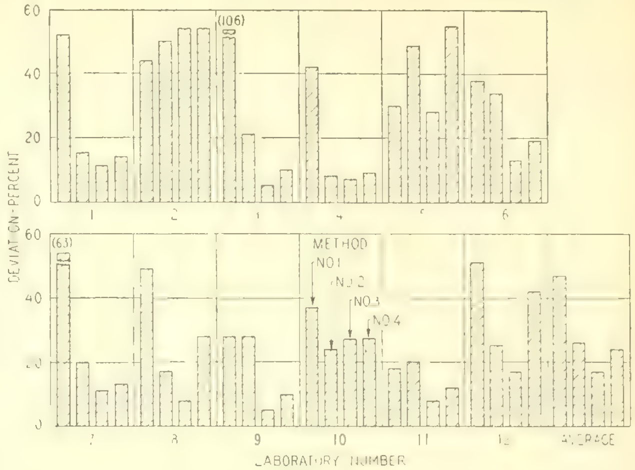

FIGURE 3.—DEVIATION OF AVERAGE RESULTS FOR EACH LABORATORY FROM AVERAGE FOR ALL LABORATORIES. VALUES ARE AVERAGES FOR ALL SANDS.

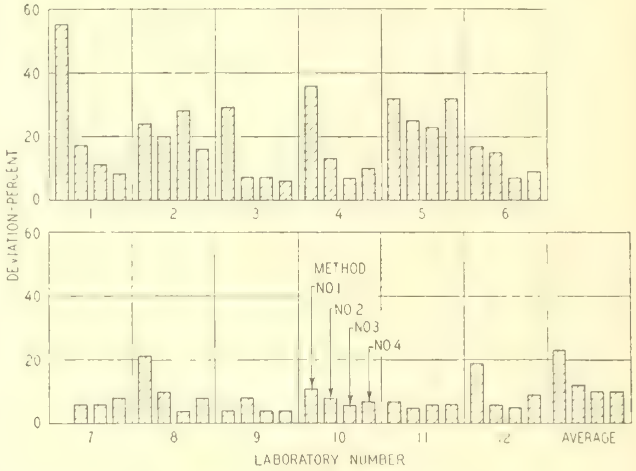

FIGURE 4.—AVERAGE DEVIATION OF INDIVIDUAL RESULTS OBTAINED IN EACH LABORATORY FROM AVERAGE RESULTS FOR THAT LABORATORY.

The cone method has been adopted by the American Association of State Highway Officials for use in their standard method of test for specific gravity and absorption of fine aggregate.[11] It has also been adopted tentatively by the Joint Committee on Methods of Test for Specific Gravity of Aggregates of Committees C–9 and D–4, A. S. T. M., for use in connection with the committees' recommendations regarding the unification of the various society methods for determining specific gravity. These recommendations are now before the two committees for consideration.

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[11] Method T–84, American Association of State Highway Officials Book of Standard Specifications for Highway Materials and Methods of Sampling and Testing, 1935.

MOTOR-FUEL CONSUMPTION, 1935

[Preliminary figures, compiled for calendar year from reports of State authorities [1]]

State	Tax rate per gallon		Date of rate change	Gross amount assessed for taxation	Amount subject to refund of entire tax	Net amount on which tax was earned	Amount taxed at full rate [2]	Amount taxed at reduced rates		Approximate amount taxed for highway use		Percentage change
	On Jan. 1	On Dec. 31						Rate per gallon	Amount	1935	1934	
	Cents	Cents		1,000 gallons	1,000 gallons	1,000 gallons	1,000 gallons	Cents	1,000 gallons	1,000 gallons	1,000 gallons	
Alabama	6	6		172,474		172,474	172,474			*172,474	*154,977	+11.3
Arizona	5	5		78,359	11,036	67,323	67,323			67,323	60,565	+11.1
Arkansas	6½	6½		131,784		131,784	120,294	(4)	11,490	*131,784	[5] 119,680	(6)
California	3	3		1,464,458	124,321	1,340,137	1,340,137			1,340,137	1,198,655	+11.8
Colorado	4	4		174,796	22,472	152,324	152,324			152,324	143,290	+6.3
Connecticut	2	3	Oct. 1	269,909	6,128	263,781	263,781			263,781	248,658	+6.1
Delaware	3	4	July 1	45,085	2,137	42,948	42,948			42,948	39,514	+8.7
Florida	7	7		256,609		256,609	256,609			*256,609	*235,698	+8.9
Georgia	6	6		264,617		264,617	264,617			*264,617	*239,435	+10.5
Idaho	5	5		70,310	6,352	63,958	63,743	2½	[7] 215	63,743	57,300	+11.2
Illinois	3	3		1,069,242	54,223	1,015,019	1,015,019			1,015,019	970,874	+4.5
Indiana	4	4		504,867	32,857	472,010	472,010			472,010	438,743	+7.6
Iowa	3	3		421,765	35,276	386,489	386,489			386,489	374,998	+3.1
Kansas	3	3		295,308		295,308	295,308			295,308	283,876	+4.0
Kentucky	5	5		201,324		201,324	201,324			*201,324	*184,369	+9.2
Louisiana	5	5		186,201		186,201	186,201			*186,201	*178,434	+4.4
Maine	4	4		119,821		119,821	114,532	1	[8] 5,289	114,532	110,924	+3.3
Maryland	4	4		217,665	12,815	204,850	203,072	3	[9] 1,778	204,850	195,663	+4.7
Massachusetts	3	3		608,021	23,788	584,233	584,233			584,233	566,735	+3.1
Michigan	3	3		809,472	41,485	767,987	767,987		(10)	767,987	698,681	+9.9
Minnesota	3	3		429,486	54,785	374,701	374,701			374,701	361,512	+3.6
Mississippi	6	6		140,808		140,808	123,291	1	[11] 17,517	123,291	112,666	+9.4
Missouri	2	2		512,654	14,304	498,350	498,350			498,350	478,764	+4.1
Montana	5	5		95,739	18,346	77,393	77,393			77,393	73,271	+5.6
Nebraska	4	5	(12)	222,584	3,419	219,165	219,165			*219,165	*214,257	+2.3
Nevada	4	4		26,209	2,163	24,046	24,046			24,046	22,355	+7.6
New Hampshire	4	4		73,903	1,911	71,992	71,992			71,992	68,641	+4.9
New Jersey	3	3		621,031	[13] 26,569	594,462	594,432	2	[14] 30	594,432	567,727	+4.7
New Mexico	5	5		62,881	4,894	57,987	57,987			57,987	51,134	+13.4
New York	3	4	Apr. 1	1,537,475	41,612	1,495,863	1,495,863			1,495,863	1,464,242	+2.2
North Carolina	6	6		312,012		312,012	305,579	1	[11] 6,433	305,579	273,686	+11.7
North Dakota	3	3		112,446	33,569	78,877	78,877			78,877	75,390	+4.6
Ohio	4	4		[15] 1,014,925	10,829	1,004,096	965,240	1	[15] 38,856	965,240	910,214	+6.0
Oklahoma	4	4		314,558	[16] 14,965	299,593	299,593			299,593	270,432	+10.8
Oregon	5	5		183,005	21,812	161,193	160,434	1	[17] 759	160,434	144,917	+10.7
Pennsylvania	3	4	July 1	1,171,439		1,171,439	1,171,439			*1,171,439	*1,113,629	+5.2
Rhode Island	2	2		114,754	8,621	106,133	106,133			106,133	102,834	+3.2
South Carolina	6	6		143,014		143,014	143,014			*143,014	*128,646	+11.2
South Dakota	4	4		112,634		112,634	97,415	2	[18] 15,219	97,415	89,245	+9.2
Tennessee	7	7		216,395	9	216,386	216,386			*216,386	*201,627	+7.3
Texas	4	4		934,453	98,511	835,942	835,942			835,942	791,005	+5.7
Utah	4	4		69,396		69,396	69,396			*69,396	*62,858	+10.4
Vermont	4	4		51,388		51,388	51,388			*51,388	*48,550	+5.8
Virginia	5	5		288,036	15,867	272,169	272,169			272,169	249,540	+9.1
Washington	5	5		274,691	22,090	252,601	252,601			252,601	239,187	+5.6
West Virginia	4	4		159,120	6,015	153,105	153,105			153,105	142,393	+7.5
Wisconsin	4	4		442,436	36,527	405,909	405,909			405,909	384,981	+5.4
Wyoming	4	4		48,241	796	47,445	47,445			*47,445	*44,111	+7.6
District of Columbia	2	2		112,539	556	111,983	111,983			111,983	103,129	+8.6
Total	Weighted average rate (approx.) 3.8 cents.			17,160,339	811,060	16,349,279	16,251,693		97,586	16,264,961	15,292,012	+6.4

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[1] A more accurate analysis of motor-fuel consumption during 1935 will be issued later. The amounts tabulated as "subject to refund" represent, for the majority of States, the amounts on which refunds were paid or allowed during the year, rather than the amounts of fuel subject to refund which were purchased or consumed during the year. The adjustments necessary in order to tabulate the amounts of such fuel actually consumed during the year have not been made on this table.

[2] In the case of States in which the tax rate changed during the year, amounts taxed at both the old and the new rate are included.

[3] 13 States do not provide for exemptions or refunds for nonhighway uses. The amounts entered for these States, indicated by stars, include both highway and nonhighway uses.

[4] Within 300 feet of border tax rate is same as that of adjacent State. Gallons taxed at 2 cents, 1,836,000; at 4 cents, 9,084,000; at 5 cents, 570,000.

[5] Estimated by State.

[6] As the 1935 figures represent both highway and nonhighway use they are not comparable with the 1934 figures. The percentage increase, based on the net amount taxed, was 4.9 percent. In obtaining the nation-wide percentage increase this slight discrepancy was neglected.

[7] Motor fuel used in aviation.

[8] 3 cents per gallon refunded on nonhighway uses.

[9] 1 cent per gallon refunded on motor fuel used in vehicles licensed to operate exclusively in cities.

[10] 1½ cents per gallon refunded on motor fuel used in interstate aviation. Amount not reported.

[11] 5 cents per gallon refunded on nonhighway uses.

[12] Tax rate 4 cents per gallon to Mar. 1, 5 cents to Sept. 20, 4 cents to Nov. 26, and 5 cents thereafter.

[13] Prior to July 1 nonhighway uses were exempted from initial payment of the tax. Beginning July 1 refunds were allowed.

[14] 1 cent per gallon refunded, prior to July 1, on motor fuel used in pleasure boats.

[15] Does not include 63,535,000 gallons of liquid fuel (kerosene, fuel oil, etc.) taxed at 1 cent per gallon but not subject to the 3-cent tax on motor-vehicle fuel.

[16] Prior to Mar. 10, agricultural uses were exempted from initial payment of the tax. Beginning Mar. 10 refunds were allowed.

[17] 4 cents per gallon refunded on motor fuel used in aviation.

[18] 2 cents per gallon refunded on nonhighway uses.

STATE MOTOR-FUEL TAX RECEIPTS, 1935

[Compiled for calendar year from reports of State authorities [1]]

State	Tax rate per gallon		Date of rate change	Receipts from taxation of motor fuel			Other receipts in connection with motor-fuel tax					Net total receipts
	On Jan. 1	On Dec. 31		Gross receipts	Refunds paid	Net receipts	Distributors' and dealers' licenses	Inspection fees [2]	Fines and penalties	Miscellaneous receipts [3]	Total	
	Cents	*Cents*										
Alabama	6	6		$10, 269, 346		$10, 269, 346	$75	$43, 691			$43, 766	$10, 313, 112
Arizona	5	5		3, 833, 502	$555, 618	3, 277, 884	250		$464		714	3, 278, 598
Arkansas	6½	6½		8, 193, 647	441	8, 193, 206		68, 118		$583	68, 701	8, 261, 907
California	3	3		43, 701, 052	3, 729, 647	39, 971, 405	12, 550				12, 550	39, 983, 955
Colorado	4	4		6, 814, 599	805, 066	6, 009, 533						6, 009, 533
Connecticut	2	3	Oct. 1	5, 730, 777	112, 654	5, 618, 123	53, 721				53, 721	5, 671, 844
Delaware	3	4	July 1	1, 550, 441	74, 009	1, 476, 432	2, 627			2, 760	5, 387	1, 481, 819
Florida	7	7		17, 865, 732		17, 865, 732	31, 240				31, 240	17, 896, 972
Georgia	6	6		15, 771, 723		15, 771, 723						15, 771, 723
Idaho	5	5		3, 469, 195	346, 451	3, 122, 744	415		21	1, 117	1, 553	3, 124, 297
Illinois	3	3		31, 698, 969	1, 638, 805	30, 060, 164		322, 271	2, 947		325, 218	30, 385, 382
Indiana	4	4		20, 178, 070	1, 314, 282	18, 863, 788	49	398, 482			398, 531	19, 262, 319
Iowa	3	3		12, 606, 917	1, 058, 282	11, 548, 635	116			367	483	11, 549, 118
Kansas	3	3		8, 830, 647		8, 830, 647	5, 215	84, 533		40, 795	130, 543	8, 961, 190
Kentucky	5	5		9, 835, 518		9, 835, 518			400		400	9, 835, 918
Louisiana	5	5		9, 345, 458	15	9, 345, 443		[4] 71, 047	479		71, 526	9, 416, 969
Maine	4	4		4, 731, 244	158, 678	4, 572, 566			230	31	261	4, 572, 827
Maryland	4	4		8, 808, 402	530, 377	8, 278, 025						8, 278, 025
Massachusetts	3	3		18, 056, 530	722, 440	17, 334, 090						17, 334, 090
Michigan	3	3		24, 030, 000	1, 244, 558	22, 785, 442	4, 330			789	5, 119	22, 790, 561
Minnesota	3	3		12, 770, 262	1, 643, 552	11, 126, 710	986	234, 562			235, 548	11, 362, 258
Mississippi	6	6		8, 368, 277	856, 102	7, 512, 175	195			(5)	195	7, 512, 370
Missouri	2	2		10, 025, 641	296, 233	9, 729, 408		105, 585	10, 308		115, 893	9, 845, 301
Montana	5	5		4, 740, 461	895, 919	3, 844, 542						3, 844, 542
Nebraska	4	5	(6)	9, 860, 659	148, 473	9, 712, 186		95, 514	1, 034		96, 548	9, 808, 734
Nevada	4	4		1, 048, 175	86, 331	961, 844	174		22		196	962, 040
New Hampshire	4	4		2, 944, 615	76, 449	2, 868, 166						2, 868, 166
New Jersey	3	3		18, 341, 548	[7] 162, 088	18, 179, 460	25, 642				25, 642	18, 205, 102
New Mexico	5	5		3, 104, 009	244, 713	2, 859, 296	18, 309				18, 309	2, 877, 605
New York	3	4	Apr. 1	57, 659, 473	1, 407, 769	56, 251, 704	59, 541				59, 541	56, 311, 245
North Carolina	6	6		18, 745, 078	385, 994	18, 359, 084		782, 457		5, 474	787, 931	19, 147, 015
North Dakota	3	3		3, 329, 689	1, 007, 078	2, 322, 611	776				776	2, 323, 387
Ohio [8]	4	4		40, 760, 442	1, 591, 656	39, 168, 786	365				365	39, 169, 151
Oklahoma	4	4		12, 430, 214	556, 291	11, 873, 923			3, 228		3, 228	11, 877, 151
Oregon	5	5		9, 059, 398	1, 120, 955	7, 938, 443				4, 410	4, 410	7, 942, 853
Pennsylvania	3	4	July 1	40, 706, 631		40, 706, 631			13	2, 196	2, 209	40, 708, 840
Rhode Island	2	2		2, 259, 538	157, 038	2, 102, 500	3, 704				3, 704	2, 106, 204
South Carolina	6	6		8, 717, 032	132, 888	8, 584, 144						8, 584, 144
South Dakota	4	4		4, 505, 370	304, 376	4, 200, 994		114, 425			114, 425	4, 315, 419
Tennessee	7	7		14, 966, 020	4	14, 966, 016						14, 966, 016
Texas	4	4		37, 640, 751	4, 041, 930	33, 598, 821				7, 264	7, 264	33, 606, 085
Utah	4	4		2, 713, 678		2, 713, 678	589		74		663	2, 714, 341
Vermont	4	4		2, 048, 561		2, 048, 561			84		84	2, 048, 645
Virginia	5	5		14, 133, 860	793, 355	13, 340, 505						13, 340, 505
Washington	5	5		13, 661, 809	1, 104, 501	12, 557, 308	10, 692		379		11, 071	12, 568, 379
West Virginia	4	4		6, 341, 406	245, 743	6, 095, 663	7, 278				7, 278	6, 102, 941
Wisconsin	4	4		17, 509, 969	1, 438, 762	16, 071, 207		178, 540			178, 540	16, 249, 747
Wyoming	4	4		1, 929, 650		1, 929, 650	2, 262				2, 262	1, 931, 912
District of Columbia	2	2		2, 208, 323	11, 114	2, 197, 209						2, 197, 209
Total	Weighted average rate (approximately) 3.8 cents.			647, 852, 308	31, 000, 637	616, 851, 671	241, 101	2, 499, 225	19, 683	65, 786	2, 825, 795	619, 677, 466

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[1] Previous tables were based on the reported earnings or assessments of the calendar year. The amounts given in this table represent actual collections of the calendar year.

[2] Inspection fees are imposed in Florida, Nevada, North Dakota, Oklahoma, South Carolina, and Tennessee, but the receipts from these fees were not reported.

[3] Includes fees for motor-fuel carrier permits, refund or exemption permits, interest on deposits, and miscellaneous unclassified receipts.

[4] Includes inspection fees on kerosene. Amount not reported.

[5] A special tax of 3 cents per gallon in Hancock County and 2 cents per gallon in Harrison and Jackson Counties is imposed for sea-wall protection. The receipts from these taxes were $133,954 in 1935. These receipts are distributed back to the respective counties.

[6] Tax rate 4 cents to Mar. 1; 5 cents to Sept. 20; 4 cents to Nov. 26; and 5 cents thereafter.

[7] Although refund law became effective on July 1, no refunds were actually paid until November. Prior to July 1 the law provided for exemptions rather than refunds for nonmotor-vehicle use.

[8] Amounts tabulated include proceeds of 1-cent tax on all liquid fuels, including kerosene and fuel oil. Gross receipts from this tax, $10,676,819; refunds, $92,266; net receipts, $10,584,553. Amount paid on nonmotor-vehicle fuels not reported separately.

STATE MOTOR-VEHICLE REGISTRATIONS, 1935

[Compiled from reports of State authorities for registration year, except as otherwise noted]

State	1935 registration period	Registered motor vehicles, private and commercial [1]					Other registered vehicles		Publicly owned vehicles, State, county, municipal [3]		1934 total registered motor vehicles	Year's change in motor-vehicle registration	
		Total motor vehicles	Passenger motor vehicles			Motor trucks, tractor trucks, etc.	Trailers and semitrailers	Motorcycles	Motor vehicles	Motor cycles		Increase or decrease	Percentage change
			Total	Automobiles (including taxicabs)	Motor busses [2]								
Alabama	Oct. 1-Sept. 30	242,676	203,687	203,376	311	38,989	5,586	694	1,118	...	225,732	16,944	7.5
Arizona	Jan. 1-Dec. 31	103,122	85,158	85,158	....	17,964	2,835	356	1,878	32	96,586	6,536	6.8
Arkansas	do	207,429	167,322	167,086	236	40,107	9,398	425	1,342	1	198,091	9,338	4.7
California	do	2,151,501	1,897,593	1,897,593	(4)	253,908	95,233	8,880	20,541	876	2,006,255	145,246	7.2
Colorado	do	284,578	256,148	256,148	....	28,430	968	901	(5)	....	274,231	10,347	3.8
Connecticut	Jan. 1-Feb. 29, 1936	375,837	313,605	312,671	934	62,232	3,092	2,021	3,189	197	354,142	21,695	6.1
Delaware	Jan. 1-Dec. 31	56,560	46,868	46,868	(4)	9,692	1,863	254	912	83	54,215	2,345	4.3
Florida	do	356,244	299,045	299,045	....	57,199	11,256	979	4,802	121	335,205	21,039	6.3
Georgia	Feb. 1-Jan. 31	394,096	328,017	327,645	372	66,079	10,823	952	(5)	....	376,993	17,103	4.5
Idaho	Jan. 1-Dec. 31	118,266	96,895	96,778	117	21,371	12,925	407	1,181	6	108,863	9,403	8.6
Illinois	do	1,525,817	1,340,340	1,340,340	(4)	185,477	14,439	4,568	7,930	723	1,456,241	69,576	4.8
Indiana	do	850,650	717,883	716,994	889	132,767	43,013	3,107	(5)	....	803,271	47,379	5.9
Iowa	do	699,016	618,487	618,487	....	80,529	[6] 50,244	1,955	[7] 4,478	53	666,440	32,576	4.9
Kansas	do	553,106	473,038	473,038	(4)	80,068	4,045	678	(5)	....	528,664	24,442	4.6
Kentucky	do	347,676	304,063	303,593	470	43,613	(8)	912	5,226	....	332,177	15,499	4.7
Louisiana	do	268,824	209,426	209,426	....	59,398	9,196	734	4,585	52	244,007	24,817	10.2
Maine	do	181,165	143,086	142,961	125	38,079	[9] 8,464	997	1,937	71	178,995	2,170	1.2
Maryland	do	345,578	297,050	296,148	902	48,528	1,750	1,435	[12] 2,500	....	332,892	12,686	3.8
Massachusetts	do	[10] 785,090	684,679	680,157	4,522	100,411	507	1,379	[11] 4,800	....	785,392	−302	0
Michigan	do	1,239,431	1,112,148	1,112,148	(4)	127,283	102,975	3,024	(5)	....	1,148,953	90,478	7.9
Minnesota	do	726,993	621,132	620,891	241	105,861	24,260	1,823	[12] 822	....	697,672	29,321	4.2
Mississippi	do	186,289	152,983	152,983	....	33,306	809	172	(5)	....	174,934	11,355	6.5
Missouri	do	766,369	650,550	650,141	409	115,819	22,550	1,607	2,017	8	739,813	26,556	3.6
Montana	do	149,712	114,170	114,170	(4)	35,542	2,256	380	1,587	....	128,336	21,376	16.7
Nebraska	do	406,189	347,135	346,859	276	59,054	20,461	998	1,855	....	406,632	−443	−.1
Nevada	do	34,858	27,983	27,878	105	6,875	847	109	576	9	32,230	2,628	8.2
New Hampshire [13]	Jan. 1-Mar. 31, 1936	117,154	93,699	93,699	(4)	23,455	3,173	1,082	352	....	113,134	4,020	3.6
New Jersey	Jan. 1-Dec. 31	888,292	763,426	758,401	5,025	124,866	4,431	4,826	9,161	674	864,641	23,651	2.7
New Mexico	do	92,457	74,212	73,837	375	18,245	889	247	978	16	82,900	9,557	11.5
New York	do	2,330,962	2,024,043	2,024,043	....	306,919	23,451	10,396	[7] 23,880	1,079	2,273,686	57,276	2.5
North Carolina	do	456,152	398,221	397,772	449	57,931	29,389	1,320	9,861	106	439,351	16,801	3.8
North Dakota	do	164,217	135,437	135,366	71	28,780	215	242	536	....	156,203	8,014	5.1
Ohio	Jan. 1-Mar. 31, 1936	1,712,051	1,541,097	1,541,097	(4)	170,954	95,216	7,095	15,406	338	1,613,265	98,786	6.1
Oklahoma	Jan. 1-Dec. 31	502,101	419,246	416,939	2,307	82,855	6,452	968	4,928	....	477,292	24,809	5.2
Oregon	do	[14] 293,554	250,970	250,377	593	42,584	3,558	1,393	3,971	....	272,102	21,452	7.9
Pennsylvania	do	1,745,401	1,516,375	1,510,837	5,538	229,026	19,732	10,115	(5)	....	1,681,202	64,199	3.8
Rhode Island	do	148,597	130,169	129,669	500	18,428	216	720	1,111	90	142,394	6,203	4.4
South Carolina	Nov. 1-Oct. 31	235,919	206,158	206,014	144	29,761	2,759	762	(5)	....	202,834	33,085	16.3
South Dakota [13]	Jan. 1-Mar. 31, 1936	179,271	152,340	152,280	60	26,931	12,568	330	1,073	10	169,975	9,296	5.5
Tennessee [13]	do	351,898	309,867	309,447	420	42,031	836	1,261	6,250	....	336,313	15,585	4.6
Texas	April 1-Mar 31	1,382,104	1,125,049	1,124,295	754	257,055	38,262	3,372	13,252	337	1,312,152	69,952	5.3
Utah	Jan. 1-Dec. 31	106,006	88,419	87,956	463	17,587	1,226	409	1,034	30	101,926	4,080	4.0
Vermont	Jan. 1-Mar. 31	81,513	72,482	72,380	102	[15] 9,031	1,321	575	(5)	....	77,921	3,592	4.6
Virginia	Apr. 1-Mar. 31	385,555	325,179	324,626	553	60,376	3,694	1,837	5,222	180	373,908	11,647	3.1
Washington	Jan. 1-Dec. 31	453,660	385,003	385,003	....	68,657	7,776	1,640	6,708	....	422,238	31,422	7.4
West Virginia [16]	July 1-June 30	241,617	212,312	211,668	644	29,305	2,189	1,007	4,280	129	223,155	18,462	8.3
Wisconsin [17]	Jan. 1-Dec. 31	754,037	623,893	623,352	541	130,144	7,610	2,554	6,915	283	709,359	44,678	6.3
Wyoming	do	69,998	55,405	55,405	....	14,593	7,279	195	600	....	64,990	5,008	7.7
Dist. of Columbia	do	171,464	153,854	152,775	1,079	17,610	1,377	675	2,002	129	163,070	8,394	5.1
Total	....	26,221,052	22,565,347	22,535,820	29,527	3,655,705	733,414	92,768	190,796	5,633	24,960,973	1,260,079	5.0

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[1] Wherever possible, transfers and reregistrations, publicly owned vehicles, and vehicles not for highway use (farm tractors, etc.) have been eliminated from these columns.

[2] A complete segregation of motor busses from other vehicles is not available. The figures given below represent common-carrier busses in most cases, although in some States contract busses and contract school busses are included. In a number of cases city busses are not included, rural and interurban carriers only being given. Where no busses are tabulated, the busses are included with automobiles, except as noted otherwise.

[3] Previous tables have included Federal vehicles. As no figures on Federal vehicles have been made available since 1931, this information has been omitted from this table. Figures on other publicly owned vehicles are incomplete. Some States give State-owned vehicles only; others exclude certain classes, such as fire apparatus and police vehicles, from registration.

[4] Included with motor trucks.

[5] Included with private and commercial registrations.

[6] Includes 46,250 light trailers licensed without charge.

[7] Includes unknown number of Federal vehicles.

[8] Trailers of 1,000 pounds capacity or more prohibited on highways, although permitted in cities under city licenses. Tractor-semitrailers registered as trucks. Light trailers permitted but not registered.

[9] Light trailers only; heavy trailers included with motor trucks.

[10] Registration transfers, approximately 163,000 passenger and 14,000 freight, deducted.

[11] Of these vehicles, approximately 1,300 are included with private and commercial registrations.

[12] Registration required every 3 years; these are 1935 registrations only.

[13] Although registration year was extended to Mar. 31, 1936, figures tabulated are for the calendar year 1935.

[14] Registration reported as follows: Gross weight 4,000 pounds or less, 270,899; over 4,000 pounds, 25,569; bus registrations (including ambulances and hearses) 644; motorcycles, 1,393. Figures tabulated represent an approximate classification based on fully classified figures reported for 1934.

[15] Light delivery trucks included with passenger cars.

[16] Figures tabulated are for the calendar year 1935.

[17] Trucks, tractors, and trailers are registered for the period from July 1 to June 30. Figures tabulated are for the calendar year 1935.

STATE MOTOR-VEHICLE RECEIPTS, 1935

[Compiled from reports of State authorities for registration year, except as otherwise noted]

State	1935 registration period	Total receipts, registration and other fees	Motor-vehicle registration fees					Registration fees, other vehicles		Total registration fees, all vehicles	Miscellaneous receipts							
			Total [1]	Passenger motor vehicles			Motor trucks, tractor trucks, etc.	Trailers and semitrailers	Motorcycles		Total	Dealers' licenses and plates	Operators' and chauffeurs' permits	Certificates of title	Fines and penalties	Transfer or reregistration fees	Other miscellaneous receipts	Estimated service charges, local collectors [3]
				Total	Automobiles (including taxicabs)	Motor busses [2]												
Alabama	Oct. 1-Sept. 30	$3,527,781	$3,511,864							$3,511,864	$15,917	(4)			$11,177		$4,740	(4)
Arizona	Jan. 1-Dec. 31	848,146	652,827	$326,020	$326,020		$326,807	$35,917	$1,238	689,982	158,164	$3,352	$27,273	$63,226	3,262	$26,570	34,481	(5)
Arkansas	do	2,525,672	2,153,216	1,370,069	1,323,632	$46,437	783,147	204,496	923	2,358,635	167,037	17,987	115,675		4,907	6,515	21,953	
California	do	10,562,502	8,668,948	5,741,640	5,741,640	(6)	2,927,308	545,287	27,427	9,241,662	1,320,840	37,439	100,403		87,390	1,021,534	74,074	
Colorado	do	2,206,930	1,680,986	1,297,454	1,297,454		383,532	15,600	1,539	1,698,125	508,805	22,449	34,490	140,196	1,531	53,222	[7] 256,917	(7)
Connecticut	Jan. 1-Feb. 29, 1936	8,392,408	6,525,178	4,875,823	4,728,038	147,785	1,649,355	15,290	8,605	6,549,073	1,843,335	85,653	1,352,315		179,621	109,416	116,330	
Delaware	Jan. 1-Dec. 31	1,011,520	762,371	520,170	520,170	(6)	242,201	20,278	887	783,536	227,984	5,685	115,143	32,976	56,549		17,631	
Florida	do	4,954,774	4,515,227	3,228,200	3,228,200		1,287,027	127,468	5,099	4,647,794	306,980	18,599	5,610	168,952		9,092	14,717	$90,010
Georgia	Feb. 1-Jan. 31	1,248,278	1,179,347	982,023	982,023		197,324	31,494	2,850	1,213,691	34,587	5,814	13,516			6,973	8,284	
Idaho	Jan. 1-Dec. 31	1,879,602	1,727,094	1,246,194	1,226,335	19,859	480,900	22,362	2,035	1,751,491	128,111	25,890	91,775				10,446	
Illinois	do	19,075,621	17,427,427	13,090,610	13,090,610	(6)	4,336,817	120,147	16,122	17,563,696	1,511,925	86,546	268,253	416,700		463,016	277,410	
Indiana	do	8,284,904	6,464,590	4,794,247	4,715,844	78,403	1,670,343	242,552	5,678	6,712,820	1,572,084	45,406	510,450	212,132	42,088	384,296	64,543	313,169
Iowa	do	9,921,731	9,498,297	7,105,178	7,105,178		2,393,119	64,412	6,655	9,569,364	352,367	47,720	51,844		1,115	180,592	71,096	(5)
Kansas	do	3,495,576	3,306,845	2,570,920	2,570,920	(6)	735,925	47,920	3,381	3,358,146	137,430	21,557	31,995			62,880	20,998	(5)
Kentucky	do	3,507,149	3,029,761	2,029,435	1,980,520	48,915	1,000,326	(8)	2,282	3,032,043	475,106	22,836	61,119		798	131,490	2,417	256,446
Louisiana	do	3,563,380	3,167,527	2,294,139	2,294,139		873,388	313,991	3,169	3,484,687	78,693	13,365	66,404		7,136		[9] −8,212	
Maine	do	3,269,770	2,526,971	1,747,279	1,735,404	11,875	779,692	[10] 36,551	5,070	2,568,592	701,178	29,980	496,298		23,200	115,739	35,961	
Maryland	do	4,099,850	2,885,996	2,355,522	2,224,761	130,761	530,474	78,116	7,006	2,971,118	1,128,732	36,418	264,736	497,600	198,858	101,705	29,415	
Massachusetts	do	6,320,396	3,853,802	2,571,108	2,463,319	107,789	1,282,694	25,634	1,863	3,881,299	2,439,097	63,763	2,307,992				67,342	
Michigan	do	17,594,552	14,815,385	10,432,998	10,432,998	(6)	4,382,387	714,170	11,423	15,540,978	2,053,574	64,812	867,662	704,651		296,043	120,406	
Minnesota	do	7,175,323	6,790,132	5,175,253	5,071,038	104,215	1,614,879	197,809	5,744	6,993,685	181,638	37,340	117,239	296	1,530		25,233	
Mississippi	do	1,740,856	1,707,370							1,707,370	33,486	2,021			29,555		1,910	(5)
Missouri	do	8,350,511	7,368,870	6,212,828	6,212,828	(6)	1,156,042	90,645	8,319	7,467,834	882,677	68,114	167,400	369,954		248,622	28,587	
Montana [11]	do	1,271,299	1,177,696	893,360	893,360	(6)	284,336	2,256	380	1,180,332	90,967	16,225	348	31,051		34,673	8,670	
Nebraska	do	1,998,644	1,826,414	1,178,317	1,158,687	19,630	648,097	28,020	1,708	1,856,142	142,502	11,524	21,240			103,612	6,126	(5)
Nevada	do	262,464	241,793	140,217	139,692	525	101,576	7,334	473	249,600	12,864	2,531			269	8,180	1,884	(5)
New Hampshire [12]	Jan. 1-Mar. 31, 1936	1,649,660	1,197,576						4,955	1,202,531	447,129	11,670	344,154		76,679		14,626	
New Jersey	Jan. 1-Dec. 31	16,629,209	11,766,467	8,158,437	7,871,010	287,427	3,608,030	163,335	9,652	11,939,454	4,689,755	59,290	3,393,589	540,458	134,819	205,791	355,808	(5)
New Mexico	do	1,108,714	1,021,679	668,306	642,776	25,530	353,373	12,899	695	1,035,273	73,441	6,937			2,077	17,936	46,491	
New York	do	43,453,082	38,149,203	27,578,741	27,578,741		10,570,462	362,089	46,732	38,558,024	4,895,058	182,744	3,033,683		405,764	1 024,508	248,359	(5)
North Carolina	do	6,614,212	6,451,069	4,577,253	4,541,570	35,683	1,873,816	(13)	4,857	6,455,926	158,286	(4)	27,008	152,174			[9] −20,896	
North Dakota	do	1,381,482	1,305,991	980,707	971,858	8,849	325,284	3,023	1,348	1,310,362	71,120	15,001		23,300		29,783	3,036	
Ohio	Jan. 1-Mar. 31, 1936	22,153,123	20,090,909	13,263,265	13,263,265	(6)	6,827,644	784,169	28,146	20,903.224	1,249,899	119,450	192,000		38,161	589,490	32,217	278,581
Oklahoma	Jan. 1-Dec. 31	3,861,366	3,283,249	2,188,100	2,137,976	50,124	1,095,149	95,824	3,791	3,382,864	478,502	36,820		246,721			194,961	(14)
Oregon [15]	do	2,761,904	2,153,637	1,287,755	1,255,559	32,196	865,882	42,892	4,410	2,200,939	560,965	18,247	372,655	139,566			30,497	
Pennsylvania	do	32,155,367	23,667,919	16,235,424	15,692,550	542,874	7,432,495	244,397	27,980	23,940,296	8,215,071	324,970	4,776,822	1,572,086	396,092	936,305	208,796	
Rhode Island	do	2,416,154	1,921,440	1,469,348	1,422,872	46,476	452,092	1,699	2,653	1,925,792	490,362	16,200	368,448			44,183	61,531	
South Carolina	Nov. 1-Oct. 31	1,848,510	1,549,703	1,220,281	1,220,281		329,422	35,321	1,214	1,586,238	262,272	14,199	171,277		27,447	17,554	31,795	
South Dakota [12]	Jan. 1-Mar. 31, 1936	1,371,026	1,309,875	1,134,330	1,132,753	1,577	175,545	18,408	426	1,328,709	42,317	13,110		22,193			7,014	
Tennessee [12]	do	3,657,572	3,489,953							3,489,953	167,619	(4)			31,642		11,907	124,070
Texas	Apr. 1-Mar. 31	15,788,234	14,923,639	10,072,846	9,969,014	103,832	4,850,793	329,849	15,147	15,268,635	519,599	41,465	148,500			185,564	144,070	(5)
Utah	Jan. 1-Dec. 31	1,071,489	957,712	636,945	623,540	13,405	320,767	16,196	993	974,901	96,588	12,524	18,368	35,366	3,082	18,641	8,607	
Vermont	Jan. 1-Mar. 31, 1936	2,300,049	1,960,938	1,440,324	1,424,903	15,421	[16] 520,614	5,687	3,701	1,970,326	329,723	24,252	248,804			51,382	5,285	
Virginia	Apr. 1-Mar. 31	5,150,755	4,573,517	3,384,626	3,338,543	46,083	1,188,891	36,069	5,137	4,614,723	536,032	48,747	67,779	230,056		149,762	39,688	
Washington	Jan. 1-Dec. 31	3,515,175	2,598,769	1,230,177	1,230,177		1,368,592	152,311	4,690	2,755,770	759,405	9,062	507,272	117,898			9,404	115,769
West Virginia [17]	July 1-June 30	4,514,993	3,584,394	2,993,002	2,971,867	21,135	591,392	48,822	4,657	3,637,873	877,120	39,548	156,058	615,754		49,634	16,126	
Wisconsin [18]	Jan. 1-Dec. 31	10,897,032	10,497,960	7,853,484	7,598,537	254,947	2,644,476	212,864	12,807	10,723,631	173.401	25,151	25,684			174,990	[9] −52,424	
Wyoming	do	482,888	448,190	296,851	296,851		151,339	21,598	429	470,217	12,671	6,493				5,492	686	
District of Columbia	do	904,901	176,169	153,894	152,815	1,079	22,275	1,377	675	178,221	726,680	4,561	301,808	95,270	280,408	31,580	13,053	
Partial totals [19]				189,003,100	186,800,268	2,202,832	75,636,029	5,576,578	314,971									
Full totals		322,776,536	274,545,892							280,437,441	42,339,095	1,823,467	21,243,089	6,428,576	2,045,157	6,896,765	2,723,996	1,178,045

[1] No segregation of registration fees by type of vehicle was available in Alabama, Mississippi, New Hampshire, and Tennessee. In these cases the total motor-vehicle registration fees include those of trailers and motorcycles except in the case of new Hampshire. Dealers licenses in Alabama and Tennessee are also included.

[2] The figures for registration fees of busses are incomplete (see preceding table, note 2). Where no fees are tabulated, the fees of busses are included with those of automobiles, except as noted otherwise.

[3] In a large number of States service charges are collected or deducted by the county or local officers who issue registrations. In the majority of cases these charges are included in the registration and other fees as listed. In a few cases estimates were made on the basis of registration figures. In the case of Oklahoma no estimate could be made with available data.

[4] Included with registration fees.

[5] Included with registration fees and other classified receipts.

[6] Included with fees of motor trucks.

[7] Includes $253,801 in $1 assessments on motor-vehicle registrations for old-age pension fund.

[8] Trailers of 1,000 pounds capacity or more prohibited on highways, although permitted in cities under city licenses. Tractor-semitrailers registered as trucks. Light trailers permitted but not registered.

[9] Negative item due to deduction of refunds.

[10] Fees of light trailers only; fees of heavy trailers included with those of motor trucks.

[11] Registration fees are collected by counties, and State does not maintain complete record. Figures given are estimates supplied by State.

[12] Although registration year was extended to Mar. 31, 1936, figures tabulated are for the calendar year 1935.

[13] Included with fees of motor trucks.

[14] Data not sufficient for estimate.

[15] Registration fees reported as follows: Gross weight 4,000 pounds or less, $1,354,495; over 4,000 pounds, $805,909; bus registrations (including ambulances and hearses), $36,125; motorcycles, $4,410. Figures tabulated represent an approximate classification based on fully classified figures reported for 1934.

[16] Fees of light delivery trucks included with those of automobiles.

[17] Figures tabulated are for the calendar year 1935.

[18] Trucks, tractors, and trailers are registered for the period from July 1 to June 30. Figures tabulated are for the calendar year 1935.

[19] Totals of columns for which fully classified figures were not available for all States.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936 AND 1937 FUNDS

AS OF JULY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287				$ 78,130	$ 39,065		$ 66,800	$ 33,400	9.0	$ 5,135,822
Arizona	3,564,709	$ 1,446,066	$ 1,166,429	81.1	594,942	453,504	20.4	69,864	49,688	1.7	1,895,088
Arkansas	4,275,929										4,275,929
California	9,508,671	1,065,965	609,074	35.0	7,161,950	4,075,850	152.5	2,029,553	1,169,576	55.3	3,654,171
Colorado	4,575,144	1,751,105	980,097	77.3	1,405,967	783,593	37.0	956,283	535,519	39.4	2,275,935
Connecticut	1,582,913				1,087,965	541,780	15.0				1,041,133
Delaware	1,218,750	52,544	26,272	8.8	387,204	193,602	25.6	73,078	36,539	1.9	962,337
Florida	3,315,558	518,283	259,142	17.9	574,442	287,221	18.4				2,769,195
Georgia	6,336,443	208,961	104,480	15.5	1,820,863	879,907	132.6	1,263,214	631,607	58.3	4,720,449
Idaho	3,065,304	670,814	390,698	101.4	1,553,371	927,444	88.8	914,371	547,159	92.9	1,200,003
Illinois	10,325,922	1,056,012	528,006	23.3	7,369,558	3,645,424	107.0	1,649,998	824,999	28.8	5,327,494
Indiana	6,184,258	1,828,021	912,738	67.2	3,987,634	1,993,735	132.2	406,423	203,080	8.9	3,074,705
Iowa	6,466,628	1,174,488	559,244	151.8	5,500,019	2,593,019	262.0	423,813	207,360	46.8	3,107,005
Kansas	6,631,085	1,046,298	522,833	292.5	4,022,952	1,962,918	397.8	1,991,258	992,282	281.5	3,153,052
Kentucky	4,611,955	1,529,997	761,272	98.8	677,381	323,696	44.1	1,411,418	671,428	36.2	2,855,559
Louisiana	3,557,930	616,385	308,192	23.4	1,943,614	971,807	67.4	572,566	286,283	15.7	1,991,648
Maine	2,177,197	715,690	357,047	21.4	1,119,810	559,905	36.3				1,260,245
Maryland	2,050,870							181,230	90,615	3.3	1,960,255
Massachusetts	3,485,364				607,382	303,691	5.1	273,066	136,533	3.2	3,045,140
Michigan	7,668,768	1,932,435	964,720	84.8	6,876,619	3,435,585	226.3	5,549,438	2,774,719	156.8	493,744
Minnesota	6,849,307	2,765,941	1,326,114	231.3	3,953,061	1,763,450	227.7	647,417	323,709	21.0	3,436,034
Mississippi	4,387,636										4,387,636
Missouri	7,601,200	1,809,227	903,383	295.8	4,418,472	2,209,236	123.8	3,138,984	1,569,381	198.0	2,919,200
Montana	5,122,333	2,043,492	1,144,019	216.3	2,315,689	1,296,554	202.4	236,314	94,120	10.3	2,587,639
Nebraska	5,167,930	1,111,261	555,551	75.9	1,657,754	848,239	182.6	2,164,543	1,082,271	152.5	2,681,869
Nevada	3,189,479	676,290	582,264	113.5	1,130,891	979,012	155.7	144,943	125,478	2.7	1,502,725
New Hampshire	1,218,750	259,282	126,620	7.6	489,093	241,221	14.6	168,481	84,002	2.2	766,908
New Jersey	3,352,469	87,925	43,962	1.0	2,030,222	1,015,111	28.9	1,321,388	574,164	10.4	1,719,232
New Mexico	3,990,023	1,017,857	618,877	95.1	2,163,562	1,337,949	107.8				2,033,198
New York	12,306,710	83,800	41,900	.2	11,824,789	5,846,152	205.0	1,107,240	546,000	18.8	5,872,658
North Carolina	5,879,466	722,172	361,002	107.7	2,951,390	1,474,300	333.3	697,345	335,057	71.8	3,709,107
North Dakota	3,918,269				191,740	101,206	.1				3,817,063
Ohio	9,131,204				6,286,768	3,036,015	86.6	1,616,492	663,228	8.9	5,431,961
Oklahoma	5,884,927	1,133,122	595,455	47.3	1,399,487	733,175	32.7	1,719,779	901,990	69.6	3,654,306
Oregon	4,089,711	624,112	378,566	20.6	2,727,373	1,582,189	85.3	685,192	405,177	29.0	1,723,778
Pennsylvania	10,695,448	297,941	148,702	5.0	7,301,541	3,649,735	107.8	2,249,971	1,115,230	33.2	5,781,781
Rhode Island	1,218,750										1,218,750
South Carolina	3,381,337				263,175	120,968	17.4	3,469,273	1,574,750	291.7	1,685,619
South Dakota	4,078,647	505,570	277,204	34.3	731,162	430,113	120.8	227,551	124,766	37.9	3,246,564
Tennessee	5,268,270	688,196	343,526	30.9	1,129,863	564,932	41.8	351,561	175,781	14.2	4,184,031
Texas	15,548,821	5,787,287	2,883,240	320.2	7,815,774	3,896,915	404.2	1,170,192	571,295	55.5	8,197,371
Utah	2,826,960	847,098	606,206	62.4	961,875	690,250	57.8	263,588	184,095	17.1	1,346,409
Vermont	1,218,750	300,055	149,362	14.9	899,621	449,773	44.4	400,797	173,325	7.7	446,290
Virginia	4,559,200	243,995	119,643	10.8	2,447,933	1,223,976	96.7	474,343	237,172	12.7	2,978,409
Washington	3,904,738	861,209	452,792	25.0	2,320,438	1,220,949	88.9	1,312,873	690,602	65.3	1,540,395
West Virginia	2,716,754	87,161	43,581	3.0	945,630	472,803	42.2	550,745	274,872	10.8	1,925,498
Wisconsin	6,090,504	943,634	471,640	34.0	4,209,668	2,047,548	139.2	2,075,957	923,099	90.4	2,648,217
Wyoming	3,121,972	2,045,492	1,249,184	213.0	478,644	278,990	61.6	1,078,274	663,186	209.4	930,612
District of Columbia											
Hawaii	1,218,750				467,855	231,167	8.2				987,583
TOTALS	243,750,000	40,555,183	21,873,037	3,066.0	120,283,273	61,713,674	4,786.0	45,105,616	22,603,537	2,280.8	137,559,752

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JULY 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,383,581	$ 3,383,581	105.3	$ 496,537	$ 496,537	22.1	$ 270,997
Arizona	2,569,841	$ 973,034	$ 927,032	64.5	1,934,751	1,398,534	125.2	231,669	125,927	11.0	118,348
Arkansas	3,352,061	953,929	951,881	70.3	1,847,687	1,831,705	217.5	497,673	495,568	68.2	72,907
California	7,747,928	986,312	923,426	85.0	5,757,833	5,610,317	145.7	1,044,145	1,031,013	17.0	183,172
Colorado	3,395,263	795,613	795,222	60.8	1,234,958	1,234,958	36.3	51,830	51,830	1.0	1,313,253
Connecticut	1,418,709	4,268	3,995		390,994	369,280	2.2	211,807	211,337	3.2	834,097
Delaware	900,310	77,601	77,601	14.6	411,131	411,131	32.6	174,293	145,453	13.6	266,125
Florida	2,597,144	63,820	63,820	5.5	2,131,328	2,113,455	76.6	209,697	209,697	5.8	210,172
Georgia	4,988,967	143,732	143,732	6.1	653,305	653,305	47.5	321,174	321,174	17.5	3,870,755
Idaho	2,222,747	412,870	412,149	36.3	1,717,653	1,657,760	137.3	116,158	93,833	9.5	59,005
Illinois	8,694,009	1,192,096	1,191,764	59.0	6,768,340	6,768,340	363.8	639,074	639,074	44.2	94,831
Indiana	4,941,255	181,441	181,441	4.8	4,827,482	4,626,370	222.2	106,585	106,585	7.8	26,859
Iowa	4,991,664	573,511	540,850	122.1	3,067,082	2,958,918	239.3	1,001,979	967,386	82.9	524,510
Kansas	4,994,975	404,692	404,692	77.5	4,296,581	4,296,095	283.6	293,269	283,944	13.4	10,244
Kentucky	3,726,271	407,582	407,582	82.0	1,973,913	1,973,913	203.7	597,137	597,137	44.3	747,639
Louisiana	2,890,429				1,186,675	1,031,517	64.8	1,944,045	1,711,897	109.9	147,015
Maine	1,676,799	310,933	310,933	14.3	1,079,997	1,079,450	46.2	217,004	217,004	9.9	69,413
Maryland	1,750,738	21,145	21,145	1.1	328,517	328,517	12.3	1,026,583	863,243	26.3	537,833
Massachusetts	3,262,885				117,754	117,754	1.1	1,320,493	1,320,493	6.8	1,824,638
Michigan	6,301,414	992,050	992,050	55.1	5,181,621	5,121,591	229.2	53,000	53,000	3.2	134,773
Minnesota	5,277,145	1,289,579	1,142,543	261.9	3,591,608	3,115,583	448.6	1,269,692	893,227	197.4	125,792
Mississippi	3,457,552	178,812	178,104	18.3	2,762,932	2,759,505	177.5	161,912	161,912	11.8	358,031
Missouri	6,012,652	1,677,574	1,632,014	461.1	3,316,449	3,316,449	288.0	862,926	859,918	40.5	204,271
Montana	3,676,416	1,082,875	1,082,875	64.7	2,525,162	2,525,162	120.6				68,379
Nebraska	3,870,739	173,404	165,087	15.6	2,795,016	2,759,041	295.5	425,974	425,974	51.9	520,638
Nevada	2,243,074	1,080,050	1,051,050	38.9	919,016	908,447	59.8				283,577
New Hampshire	945,225	63,802	62,520	3.6	361,141	347,753	13.3	178,467	175,075	9.0	359,877
New Jersey	3,129,805				2,158,920	2,158,920	18.4	136,333	136,333	1.4	834,552
New Mexico	2,871,397	1,004,960	1,004,960	93.9	1,160,488	1,160,488	72.6	262,129	262,129	16.2	443,820
New York	11,046,377	753,983	743,037	7.8	9,957,475	9,556,620	154.1	263,000	263,000	4.7	483,719
North Carolina	4,720,173	272,901	272,901	24.4	3,135,676	3,103,087	209.5	640,970	589,887	39.4	754,298
North Dakota	2,867,245	243,587	243,587	42.6	1,036,920	1,034,711	124.1	1,287,674	1,287,674	126.6	301,272
Ohio	7,670,815	399,620	399,620	4.3	3,959,803	3,931,978	75.5	1,879,605	1,768,906	141.0	1,570,310
Oklahoma	4,580,670	347,695	347,641	37.7	2,284,571	2,281,066	195.3	1,104,077	1,103,556	134.9	848,408
Oregon	3,038,642	423,144	421,269	20.7	2,332,611	2,241,719	119.9	539,972	261,372	26.2	114,282
Pennsylvania	9,347,797	287,881	262,118	11.5	1,780,765	1,740,831	64.9	1,078,504	1,073,504	67.2	6,266,344
Rhode Island	989,208	140,528	140,528	1.6	846,817	846,817	17.4				1,863
South Carolina	2,702,012	124,976	123,773	15.5	1,677,027	1,640,431	151.6	424,798	423,537	46.2	514,272
South Dakota	2,976,454	567,178	567,178	162.8	1,546,931	1,546,931	225.1	304,954	304,954	42.9	557,391
Tennessee	4,192,460	254,922	254,922	4.4	2,240,658	2,240,658	95.8	599,051	599,051	25.9	1,097,829
Texas	11,989,350	3,550,282	3,251,462	378.9	8,606,508	7,845,757	699.4	987,870	841,609	39.6	50,523
Utah	2,067,154	530,337	519,031	46.6	1,008,648	966,358	86.1	396,884	306,128	26.7	275,536
Vermont	924,306	213,437	200,691	6.5	777,835	659,233	14.9	30,109	28,934	.4	35,387
Virginia	3,652,667	1,023,936	983,063	385.1	1,705,990	1,693,624	560.6	653,865	640,119	89.5	335,862
Washington	3,026,161	872,055	810,504	54.2	2,155,682	1,888,822	91.3	296,070	255,729	16.2	71,106
West Virginia	2,231,412				1,333,391	1,329,894	51.4	571,357	571,315	23.8	330,203
Wisconsin	4,823,884	505,796	488,739	51.1	4,727,732	4,119,668	273.8	234,329	215,477	15.9	
Wyoming	2,219,155	256,351	256,348	14.2	1,796,937	1,796,919	119.9	54,654	54,653	4.8	111,235
District of Columbia	949,496	724,656	700,626	6.0	251,210	216,234	2.5				32,636
Hawaii	926,033	93,330	80,570	1.3	549,947	541,611	7.6				303,852
TOTALS	195,000,000	26,632,280	25,736,076	2,994.2	121,595,049	117,240,808	7,427.4	25,199,328	23,451,165	1,717.7	28,571,951

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JULY 31, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
				NUMBER					NUMBER					NUMBER			
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 9,124	$ 9,124	1			$ 3,178,723	$ 3,178,723	32			$ 704,414	$ 704,414	8		11	$ 142,355
Arizona	1,256,099	47,412	47,412	1			1,002,163	986,483	10			86,220	63,832	1			158,371
Arkansas	3,574,060	396,873	394,996	12			1,505,139	1,501,881	22	5		1,655,792	1,653,103	22		29	24,081
California	7,486,362	466,411	451,116	6	3		6,946,051	6,714,198	46	4							321,048
Colorado	2,631,567	550,989	529,989	7			964,639	964,639	16								1,136,939
Connecticut	1,712,684						78,774	78,774		1		79,677	79,677	1			1,554,233
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	15,489	15,489		1		1,741,112	1,738,801	17	4		340,039	340,039	8			733,554
Georgia	4,895,949						276,256	276,256	5	1		230,061	230,061	6			4,389,632
Idaho	1,674,479	93,565	93,565	1			936,692	936,692	17	1		96,366	90,000	1			554,222
Illinois	10,307,184	84,015	84,015	4			5,160,753	5,160,753	44	2		2,589,904	2,589,904	12	1		2,472,512
Indiana	5,111,096						4,499,732	4,377,088	36	7		824,914	501,186	2	3	161	232,822
Iowa	5,600,679	26,763	25,500	1	2		3,417,483	3,312,197	67	6		1,657,471	1,648,868	27	2	6	614,113
Kansas	5,246,258						4,518,794	4,518,794	42	1		727,464	727,464	11		3	
Kentucky	3,672,387	15,290	15,290	1			2,443,349	2,153,617	18			264,339	264,339	4	3		1,239,142
Louisiana	3,213,467						814,208	814,208	7	1		1,608,180	1,560,001	14	3		839,259
Maine	1,426,861	60,837	60,504	1			574,409	573,818	12			297,093	297,093	5		1	495,447
Maryland	2,061,751						414,161	414,161	3	2		967,014	944,545	3	2	11	703,045
Massachusetts	4,210,833						1,591,534	1,591,534	12	2		334,460	334,460	4			2,284,839
Michigan	6,765,197	489,625	489,625	5	1		5,646,177	5,601,677	37	6							673,895
Minnesota	5,395,441	353,423	353,423	14		8	3,046,507	3,040,457	52	8	5	723,774	723,774	13	1	28	1,277,787
Mississippi	3,241,475						1,953,738	1,953,738	42	3		286,260	286,260	5		1	1,001,477
Missouri	6,142,153						4,362,626	4,349,324	31	1		1,534,151	1,525,769	13		2	267,060
Montana	2,722,327	574,892	574,892	9	2		2,019,089	2,019,089	27	4							128,345
Nebraska	3,556,441	199,361	199,361	4			1,946,376	1,946,376	65	1	1	1,280,515	1,280,515	10	1	22	130,189
Nevada	887,260	306,096	306,096	7			379,746	379,746	3								201,418
New Hampshire	822,484						354,902	354,902	3	3	1						467,582
New Jersey	3,983,826						1,159,350	1,159,350	6	2		542,110	542,110	6			2,282,366
New Mexico	1,725,286	272,505	272,505	6			693,593	693,593	5	1		647,939	637,866	6			121,323
New York	13,577,189	19,640	19,640		1		9,699,184	9,438,638	32	30		636,050	635,770		5		3,483,141
North Carolina	4,823,958	94,809	94,809	1	2		1,649,075	1,649,075	21	8		905,934	889,535	12	4		2,190,538
North Dakota	3,207,473	39,335	39,335	1			1,347,422	1,346,422	24			667,297	667,297	14	1		1,154,420
Ohio	8,439,897						1,867,025	1,774,786	11	1		2,160,847	2,038,598	17	2		4,626,513
Oklahoma	5,004,711	402,404	402,404	8	1		1,675,196	1,675,196	26	1		1,402,699	1,402,699	20	1		1,524,412
Oregon	2,334,204	36,709	36,709	1			1,987,879	1,863,168	12	6		434,327	434,327	4		2	
Pennsylvania	11,483,613	10,836	10,836	3			3,792,062	3,586,259	30	9		2,678,263	2,264,598	23	5		5,621,921
Rhode Island	699,691						654,008	654,008	4	1							45,683
South Carolina	3,059,956						1,368,967	1,358,001	27	5	2	571,285	570,875	11		29	1,131,080
South Dakota	3,249,086	77,597	77,597	4			829,820	829,820	20			769,273	769,273	17	1	6	1,572,397
Tennessee	3,903,979	21,428	21,428	1			534,900	534,900	11	1	2	441,257	441,257	10	1	16	2,906,393
Texas	10,855,982	312,659	312,659	10			7,357,872	7,351,673	85	12		2,982,735	2,929,520	28	3	149	262,129
Utah	1,230,763	29,757	29,757		1		608,107	608,107	9			165,398	140,000	2			452,899
Vermont	729,857	164,673	164,678	3	3		297,333	295,975	4	2		76,786	74,992	2		10	194,212
Virginia	3,774,287	172,632	172,632	11			1,383,605	1,312,742	22	2		675,769	634,609	18	2	9	1,654,304
Washington	3,095,941	230,418	230,418	3	2		1,767,038	1,762,207	12	6	1	639,941	639,941	5	3	6	462,474
West Virginia	2,677,937						438,108	438,108	3	1		455,602	455,602	4			1,784,227
Wisconsin	5,022,683	211,231	211,231	3			2,594,410	2,594,410	25	5		1,320,424	1,320,424	5	1		896,618
Wyoming	1,360,841	55,366	55,365	2			325,013	325,011	3			627,191	587,664	4			392,801
Dist. of Columbia	410,804						423,907	409,259	3								1,545
Hawaii	453,703						296,218	295,333	3			215,430	158,369	2			1
TOTALS	196,000,000	5,842,169	5,802,400	131	19	8	102,666,711	101,013,967	1065	156	12	35,304,665	34,080,630	380	45	502	55,103,003

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

DEPARTMENT BULLETINS

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

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No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T . . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction.

No. 191 . . . . Roadside Improvement. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF JULY 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,264,342	$ 14,723,902	$ [illegible]	$ 3,193,535	779.3	$ [illegible]	$ 160,296	$ 646,015	35.2		$ 453,670	2.9	$ 6,167	$ 56,622
Arizona	5,211,960	2,641,935	8,989,074	5,204,513	2,579,530	543.0	12,500		12,500					7,447	49,905
Arkansas	6,748,335	3,428,049	10,902,752	6,636,112	3,296,968	618.0	62,020		51,965	1.1	$ 9,241	49,945	1.4	102,981	19,172
California	15,507,354	7,932,206	29,429,219	15,583,249	7,584,383	759.6	1,293,183		290,015	.9		820		18,105	56,988
Colorado	6,874,530	3,486,006	11,177,865	6,831,431	3,441,857	636.3								43,099	44,149
Connecticut	2,865,740	1,454,303	4,061,019	2,769,068	854,239	69.3	483,548		443,705	4.8	40,533			36,119	141,924
Delaware	1,814,088	923,395	2,576,358	1,818,804	815,188	128.3	56,002		56,002	.5		52,205	1.1	284	
Florida	5,231,834	2,661,343	8,556,787	5,175,534	2,114,469	290.7	468,731		437,733	12.2		15,955	.8	56,300	93,165
Georgia	10,091,165	5,113,491	12,166,863	9,026,532	2,483,466	694.3	1,957,935	563,377	1,340,534	115.4	213,756	85,519	18.0	276,520	1,296,971
Idaho	4,426,249	2,277,486	6,515,368	4,416,568	1,737,381	441.8	429,730		425,402	4.7	42,906	37,043		26,776	27,659
Illinois	17,576,770	8,901,401	23,808,620	16,387,551	6,603,392	649.3	3,303,516	1,040,808	2,156,062	52.3	44,638	13,740	14.7	97,774	142,207
Indiana	10,937,843	5,088,963	14,449,277	9,777,926	4,025,937	443.8	1,166,876	203,943	836,582	44.7		134,587	.4	55,974	31,887
Iowa	10,955,600	5,116,361	15,333,141	10,955,560	4,681,121	1,216.5	412,102		384,800	8.5		47,440	3.3		
Kansas	10,061,504	5,117,675	15,313,097	9,971,349	5,005,778	1,126.9	213,397	68,563	106,757	14.4	9,000	5,140	.9	40,201	
Kentucky	7,517,359	3,816,311	11,032,739	7,067,455	3,146,455	793.6	776,141	411,849	331,140	16.8	7,838	176,365	2.7	10,217	114,352
Louisiana	5,328,571	2,903,932	8,714,663	5,616,736	2,466,942	236.1	401,032	138,621	248,348	17.1	56,549	72,943	6.4	16,635	175,043
Maine	3,369,317	1,711,586	[illegible]	3,337,541	1,657,506	143.1	7,234		7,234		10,573			21,803	46,846
Maryland	3,564,527	1,810,058	4,850,828	3,150,339	714,205	128.2	846,904	391,728	53,462	28.4		163,983	3.4	82,420	448,407
Massachusetts	6,597,100	3,350,474	7,467,342	4,582,227	2,241,385	112.4	2,713,189	1,546,850	816,339	2.9		114,280	.3	118,022	178,471
Michigan	12,736,727	6,452,568	19,737,477	12,636,114	5,517,976	728.8	872,325		814,348	39.5		28,925		40,113	91,320
Minnesota	10,656,569	5,425,551	16,078,567	10,495,068	4,713,102	1,633.2	395,722	16,282	333,564	13.2		64,328	3.6	145,218	314,558
Mississippi	6,978,675	3,540,227	11,867,417	6,584,009	2,402,426	678.1	1,403,103	336,141	1,057,996	65.9	4,437	34,395	.9	54,088	44,909
Missouri	12,180,366	6,173,740	16,731,927	11,154,098	4,577,390	1,431.8	2,661,061	937,793	1,455,324	19.5		108,538	.4	88,505	2,488
Montana	7,439,748	3,763,734	11,373,085	7,324,443	3,380,520	1,029.9	460,934	64,459	323,489	28.4				50,846	65,725
Nebraska	7,373,961	3,964,364	12,547,646	7,714,817	3,572,168	1,036.2	636,363	70,773	273,550	37.1		98,740	8.7	48,371	19,905
Nevada	4,545,917	2,306,356	6,771,659	4,499,583	1,984,131	741.9	272,217		272,217	12.1	23,736	5,250	6.5	22,598	35,698
New Hampshire	1,909,839	969,462	2,973,832	1,904,951	937,565	77.7						6,482		4,888	25,396
New Jersey	6,346,939	3,220,470	7,756,636	6,126,421	1,126,624	81.5	1,784,114		1,565,161	5.8	197,208	303,276	8.4	112,410	205,818
New Mexico	5,742,935	2,941,790	8,664,309	5,525,342	2,805,137	762.8	50,695		33,710	2.3				167,593	102,853
New York	[illegible]	11,317,921	38,331,567	21,543,282	9,645,914	802.1	[illegible]	616,674	1,279,849	21.1	70,947	151,620	.2	143,988	50,488
North Carolina	9,522,993	4,840,941	14,541,762	9,036,263	4,283,185	1,329.1	473,671	212,461	260,710	20.9	100,071	295,439	5.6	172,997	91,607
North Dakota	5,834,448	2,938,967	7,760,885	5,578,194	1,491,544	2,030.0	851,765	74,977	723,779	98.8	26,322	195,253	16.7	124,955	528,390
Ohio	15,444,592	7,865,012	23,778,287	15,301,932	6,679,773	770.3	1,117,240	45,350	1,007,640	24.3	27,376	52,706	1.7	59,285	128,893
Oklahoma	9,215,736	4,585,180	14,099,927	9,133,731	3,993,691	804.0	490,905	67,007	422,163	2.1		6,250	.4	16,060	263,076
Oregon	6,106,896	3,037,814	9,532,136	5,965,059	2,659,661	462.4	466,132	64,950	395,644	6.4		25,041		73,888	107,468
Pennsylvania	18,531,004	9,540,788	27,745,680	18,147,273	8,262,022	1,011.3	1,303,427	456,292	753,541	47.2	34,552	270,282	3.2	252,887	298,943
Rhode Island	1,998,708	1,014,572	3,148,010	[illegible]	1,014,572	89.1									
South Carolina	5,459,165	2,770,954	7,336,795	5,217,163	1,870,355	589.0	785,787	121,449	641,929	35.9	11,408	96,684	2.9	109,125	155,985
South Dakota	6,511,479	3,947,643	8,751,168	5,716,722	2,456,707	1,111.6	565,788	83,443	496,345	31.5	18,974	6,687	16.7	184,341	85,844
Tennessee	[illegible]	4,302,991	12,678,279	8,366,445	3,406,825	475.8	953,882	124,174	733,910	16.9		19,868	.1		142,389
Texas	24,244,024	12,291,363	37,334,479	23,329,962	11,648,828	2,774.2	952,895	325,262	532,648	11.9		500	7.1	88,760	109,277
Utah	4,194,708	2,122,591	7,123,928	4,102,416	1,943,960	566.5	[illegible]		156,741	4.4	[illegible]	31,762			228
Vermont	1,367,573	948,007	3,032,919	1,363,531	837,747	137.6	123,086	3,922	[illegible]	[illegible]		5,299	.7	[illegible]	11,350
Virginia	7,416,757	3,765,387	11,445,708	[illegible]	3,266,198	587.6	221,340	17,720	202,770	27.8	56,178	24,235	2.9	110,157	272,184
Washington	6,115,867	3,120,412	9,244,404	6,096,252	2,907,420	302.4	121,628		115,530	.3	13,790	46,596		3,325	36,866
West Virginia	4,474,234	2,280,335	5,372,312	4,311,372	1,263,459	196.1	942,272	84,032	801,733	25.9		89,815	1.2	68,830	99,329
Wisconsin	9,724,881	4,941,337	15,253,645	9,676,693	4,771,158	613.2	129,000	7,300	79,318	.5		41,376		40,338	39,385
Wyoming	4,531,707	2,237,712	6,343,611	[illegible]	2,155,179	1,075.9	47,679	11,728	30,962	1.8		28,905		20,702	62,666
District of Columbia	1,918,469	973,342	2,747,515	1,909,584	837,795	[illegible]	120,199		84,599	1.5				8,885	51,348
Hawaii	1,871,062	943,778	2,602,372	1,870,383	[illegible]	50.6	740,023		736,463	5.2		23,433		679	9,019
TOTALS	394,000,000	200,000,000	599,105,932	381,229,355	165,508,162	[illegible]	37,099,523	[illegible]	[illegible]	971.3	917,324	3,427,876	144.2	[illegible]	6,288,373

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 7 ▽ SEPTEMBER 1936

PLACING TARRED FELT ALONG A LONGITUDINAL JOINT

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - - - - See page 2 of cover for prices

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Volume 17, No. 7 September 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

THE STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **L. W. TELLER**, Senior Engineer of Tests, and **EARL C. SUTHERLAND**, Associate Highway Engineer

PART 4.—A STUDY OF THE STRUCTURAL ACTION OF SEVERAL TYPES OF TRANSVERSE AND LONGITUDINAL JOINT DESIGNS[1]

PRECEDING REPORTS on parts of this investigation have presented: (1) A general description of the entire project and of the methods employed in making the tests (part 1); (2) a discussion of the effects of temperature and moisture variations on the size, shape, and load-carrying ability of pavement slabs as observed during the course of these studies (part 2); and (3) a discussion of the results of tests on various pavement cross-sections (part 3).

This report contains a description of the studies that were made of the structural action of the several transverse and longitudinal joints included in the investigation. In presenting this material, certain descriptive matter will be repeated from the preceding reports for the purpose of amplification together with such data from parts 2 and 3 as are necessary for an adequate treatment of the subject.

In dealing with the subject of the design and use of joints in concrete pavements, it is of considerable interest to look backward over the period of concrete pavement construction and trace the development of theory and practice in regard to joint construction. This development will be sketched rather briefly.

A number of concrete pavements were built in Europe and in the United States long before the beginning of the present century. There is mention of one constructed in Inverness, Scotland, as early as 1865,[2] while in this country one of the earliest of which there is an authentic record is that constructed in Bellefontaine, Ohio, in 1892. So little information is given in the accounts of these early concrete pavements that in most cases no details of the spacing and design of the joints are available. It appears, however, that the joints were simply small spaces left between adjacent slabs and were intended to be filled with earth, although as far back as 1871 a patent was granted that gave the inventor rights covering the use of gum, tar, rubber, or other water-repellent substances as a filler for joints in pavements made of concrete blocks.[3] Some mention is made in engineering literature of the use of pitch and of creosote oil for the same purpose at about the same time.

EARLY JOINTS DESIGNED TO PROTECT SLAB EDGES FROM DAMAGE BY STEEL-TIRED WHEELS

The Bellefontaine pavement was laid in small slabs or blocks 5 or 6 feet square and tarred paper was placed between the blocks to allow for expansion.[4] It is interesting to note that with this small-slab construction practically no cracking has occurred in this pavement during more than 40 years of service. At the time it was constructed all traffic was carried on steel-tired wheels and much damage was done to the edges of the slabs by teamsters who drove so that their wagon wheels followed the joints.[5] Efforts to protect slab edges from the damaging action of steel-tired wheels seem to have been the dominant throught in the early consideration of joint design.

Figure 1 shows a drawing of what is one of the first, if not the first, joint designs for concrete pavements patented in this country.[6] The object of this design, as stated in the patent, was to allow adjacent blocks to heave without injury to their edges. Direct expansion apparently was not a consideration. It was specified that the metal forming the joint should be stiff enough to permit tamping the concrete around it, yet light enough to crush in the event that heaving occurred.

The decade between 1900 and 1910 might well be considered as the early formative period in concrete pavement history. A new type of pavement was developing and the literature of this period contains many inquiries as to how concrete roads should be built, with little or no information available to supply the answers. The joint, intended to provide for expansion and to control cracking, made its appearance, although it continued to be a simple opening between slabs. Breaking of the slab edges under the action of the steel-tired wheels was still a serious problem and its effect is reflected in the staggered and oblique joint designs of the period. Some pavements of which there is a record of the joint construction are described briefly as follows:

Grand Rapids, Mich., 1901–02: In a two-course pavement, joints were placed along the curbs and transversely at intervals of 25 feet in the base course. The width of these joints is not recorded. The top course was laid in alternate blocks 6 feet square with expansion joints one-fourth inch in width between blocks. These joints were filled with asphalt.

Toronto, Canada, 1902: This pavement was laid in blocks 20 feet square with ¾-inch expansion joints between the blocks. The joints were filled with "paving pitch." It is reported that under heavy traffic the edges of the slabs shattered badly.

Richmond, Ind., 1903–04: The earliest concrete pavements in this city date from 1896. Of the early pavements no information about the joint design was found, although it appears that small slabs were used. The pavements laid in 1903–4 were in large slabs with expansion joints 1 inch wide. It was reported that these wide joints were troublesome because of chipping at the slab edges. Mention of temperature cracking in connection with this pavement appeared in the early reports.

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[1] A series of five articles has been planned. Parts 1, 2, and 3 have appeared in PUBLIC ROADS, vol. 16, nos. 8, 9, and 10, October, November, and December 1935, respectively. Because of its length, Part 4 will be presented in two issues of PUBLIC ROADS. The second installment will appear in the October issue.

[2] Cement and Concrete—A general refrence book, 1929. Portland Cement Association, p. 49.

[3] United States Patent no. 120268 granted Oct. 24, 1871, to H. A. Gunther.

[4] Portland Cement Pavement, by G. W. Bartholomew, Jr., Engineering News, vol. 33, no. 1, Jan. 3, 1895, p. 5.

[5] The Concrete Pavements of Bellefontaine, Ohio, by Prof. F. H. Eno, Engineering News, vol. 51, no. 1, Jan. 7, 1904, p. 15.

[6] United States Patent no. 312897 granted Feb. 24, 1885, to C. F. Rapp.

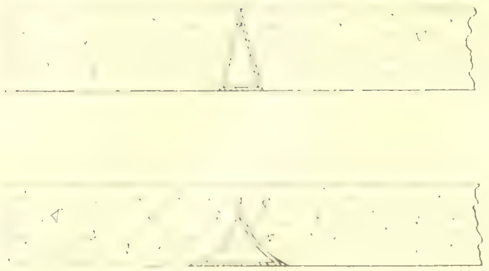

FIGURE 1.—ONE OF THE FIRST JOINT DESIGNS FOR CONCRETE PAVEMENTS PATENTED IN THE UNITED STATES.

Washington, D. C., 1906: This pavement was laid in slabs 100 feet long separated by 1-inch joints filled with a bituminous material.

City of Panama, 1906–7: It is recorded that the first concrete paving in this city consisted of slabs 10 feet in length. On wide streets the pavement was divided longitudinally at the center and the slabs were staggered on either side of this joint.

Because of difficulties with chipping and spalling along the joints, commercial companies specializing in concrete pavement construction began gradually to increase the spacing between joints. This practice continued for many years and culminated in the construction of hundreds of miles of concrete pavements in which the only joints constructed were at places where the paving operation was stopped for some reason.

That some engineers at this time appreciated the advantages of crack control in concrete pavements is evidenced by the following quotation from a patent for a joint design granted to Mr. R. Kieserling, a German citizen, by the United States Patent Office in 1906: [7]

"As it is well known, irregularly running cracks appear after a short time in paving made from concrete or other cement mixtures, which lead to the destruction of the pavement. * * * I avoid this irregular formation of cracks by providing for the occurrence of cracks at definite places and causing them to run in a direction previously determined upon." Mr. Kieserling's design for accomplishing this control of cracking is shown in figure 2.

WIDE DIFFERENCES FOUND IN STRUCTURAL DETAILS OF EARLY JOINTS

By 1910 the automobile had demonstrated itself to be a practical machine and with its increasing use came the demand for more and better highways, particularly interstate highways. The stimulus thus given to road building is reflected in the increased discussion of concrete pavement design. Spalling and chipping at the joints and separation of adjacent slabs, both vertically and horizontally, were troubles which gave a great deal of concern in these early pavements. To overcome chipping, diagonal joints and edges armored with metal were frequently recommended. For the displacement at the joints, particularly the longitudinal joints, numerous suggestions appeared—more attention to drainage, reinforcement to prevent longitudinal cracks, dished subgrade to provide a thicker pavement at the center of the road, and rolled stone subbases—each had its advocates.

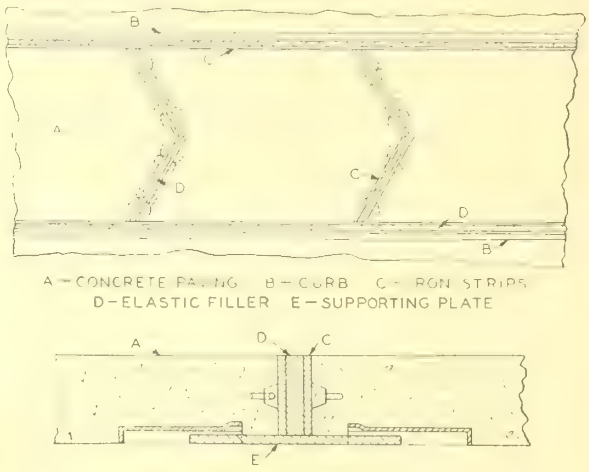
A
B
C
D
E
A — CONCRETE PAVING B — CURB C — IRON STRIPS
D — ELASTIC FILLER E — SUPPORTING PLATE
PATENT GRANTED 1906
NO. 839,600 — R. KIESERLING

FIGURE 2.—AN EARLY PATENTED JOINT DESIGN FOR CONCRETE PAVEMENTS.

Speaking editorially, one of the leading engineering journals of the country said of the concrete pavement joint designs of this period: [8]

> Practice exhibits a heterogeneous array of expansion joint details, spacings, and arrangements. This is most true of transverse joint practice. The plan is general of placing joints between pavement edge and curb and, when railway tracks occupy the streets, of placing joints on each side of the tracks just outside the tie ends. There is no similar uniformity in transverse expansion joint practice. They are spaced 25, 30, 37½, 50, 60, and 100 feet apart, and the most common spacings are perhaps 25 and 30 feet. Usually they are square across the roadway but various diagonal arrangements are employed. Structurally the differences are wide. Joints with metal guard plates, joints with rounded edges only, joints of all widths from ¼ to 1 inch, joints with fillers of a dozen characters are employed.

As mentioned previously, some of the State highway departments adopted the practice of laying concrete pavements without joints except at points where the construction operation was stopped. By 1915 a number of States were building their pavements in this manner. The reasons prompting this policy were described by one State highway engineer,[9] who stated that the occurrence of transverse cracks had been almost as erratic in pavements with the joints spaced 50 feet apart as in those in which the spacing was 100 feet. The difficulty of constructing smooth surfaces in the vicinity of the joints and the chipping of the slab edges at the joints under the action of traffic were also important considerations.

At the tenth annual convention of the American Concrete Institute (1914) certain recommended specifications for concrete pavement construction were adopted, and the recommendations relative to joint construction probably reflect the thought as to the best practice at that time.

In these specifications it was recommended that transverse joints should be not less than one-fourth nor more than three-eighths inch in width and should be placed across the pavement perpendicular to the center line, not more than 35 feet apart. It was further recommended that a longitudinal joint not less than oneourth inch in width should be constructed between he curb and the pavement and that all joints should xtend completely through the pavement and be perendicular to its surface. Also, the concrete at transerse joints should be protected with soft-steel, joint-rotection plates rigidly attached to the concrete, the urface edges of the metal plates to conform to the suraces of the concrete. All joints found to be more than ne-fourth inch too high or one-half inch too low were o be removed. It was specified further that all joints vere to be formed by inserting, during construction, and eaving in place the required thickness of joint filler, his filler to extend through the entire thickness of the avement.

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[7] United States Patent No. 839600, granted Dec. 25, 1906, to R. Kieserling, Germany.

[8] Engineering and Contracting, vol. 40, no. 2, July 9, 1913.

[9] H. E. Bilger, State road engineer of Illinois, in a paper delivered before the Illinois Society of Engineers and Surveyors 1915. Also Engineering and Contracting, vol. 43, no. 11, Mar. 17, 1915, pp. 254–5.

N 1917 LOAD TRANSFER APPEARED AS A FACTOR IN JOINT DESIGN

It will be observed that provision for expansion and rotection of the joint edges are dominant consideraons and that mutual support through transfer of load s not mentioned as a joint requirement. The smoothess tolerances are of interest in contrast with the pecifications of today.

Load transfer as a factor in joint design was soon to ppear, however. In the design of a concrete paveent constructed between two Army camps near Newport News, Va., during the winter of 1917–18, teel dowels were placed across all transverse joints for he stated purpose of transmitting load across the oint by shear.[10] The joints were three-eighths inch in idth and four three-quarter inch diameter steel dowels ere used in the 20-foot pavement width. It was recomended that eight rather than four dowels be used. Heavy truck traffic during the World War period aparently failed to damage these joints.

Following the World War the use of steel dowels pread rapidly wherever concrete pavement was being id and has continued up to the present time.

Although the principle had been well known for any years, one of the earliest references to the use of he weakened-plane contraction joint for crack control ppears in connection with a pavement laid in West irginia in 1919.[11] It was constructed by grooving the ottom of the slab by setting a thin board on edge on he subgrade, the width of the board being approxiately one-half the thickness of the pavement. The oncrete was then cast over the board.

Soon after this the recommendation appeared that his type of joint be formed by a board one-fourth inch hick and 6 inches wide so cupped or warped as to ive a tongue-and-groove effect to adjoining slabs, thus reventing uneven settlement of the abutting edges.

Figure 3 shows typical joint designs for which patents ere granted in this country during the decade followg 1910. The essential feature of the design shown in gure 3–A was the use of steel protection plates at the oint edges, tied in to a general system of reinforcement. he object of the design shown in figure 3–B was to ermit the placing of the joint filler in advance of the oncreting operation. It will be noted that an air hamber was provided to take care of the filler material uring expansion. Figure 3–C shows a design intended protect the edges of the slabs and at the same time erve as a container for the filler.

The use of a steel T-section embedded in the plastic ller material was proposed in the design shown in gure 3–D, the T-section presumably serving to protect he edges of the concrete. While the design shown in figure 3–E was apparently intended primarily to provide a sliding key or bridge in order to hold the filler material, both the design and the claim contain the germ of an idea that appears in many of the joint designs being promoted today. Figure 3–F shows a heavily armored expansion joint in some respects quite similar to designs recently proposed although the idea of load transfer does not appear in the claims.

The design shown in figure 3–G is definitely intended to provide "an interlocking engagement of the adjacent concrete sections" although the compressible material which is interposed between the corrugated plates, together with separation caused by contraction, would probably completely defeat the purpose. Figure 3–H shows a design that includes the use of dowels which are not bonded to the concrete, and are installed for the stated purpose of maintaining the engaged sections of concrete in the proper relation to each other and at the same time permitting independent expansion and contraction.

NEED FOR BETTER EXPANSION AND CONTRACTION JOINTS RECOGNIZED

The disappearance of steel-tired vehicles from the highway, a change which accelerated rapidly during the period following the World War, eliminated what had been one of the worst problems in joint design, i. e., chipping of the slab edges. The result was the general omission of the steel, edge-protection plates from joint designs. A new trouble appeared, however, with the increased use of concrete pavements. Expansion failures known as "blow-ups" began to appear 3 or 4 years after the laying of the pavement, and the seriousness of some of these created a renewed interest in joints providing relief for expansion.

The desire to improve the appearance of concrete pavements by control of cracking led to the more widespread use of the so-called "contraction joints." As already noted, the earliest joints of this type were constructed by grooving the bottom of the slab. The irregularity of the crack on the slab surface, coupled with the difficulty in sealing these joints effectively, led to an unfavorable reaction which resulted in the general abandonment of this design. Shortly after 1920 a weakened-plane joint appeared in which the upper surface of the slab was grooved. While more difficult to construct, it obviated the difficulties just noted and, with the development of mechanical methods for grooving the concrete at the time of construction, this type of contraction joint came into rather widespread use.

The decade following 1920 also saw the general adoption of longitudinal joints that divide the pavement into slabs approximately 10 feet wide. Experience showed that such joints practically eliminated longitudinal cracking and, since this width is about what is required for a single lane of traffic, the practice of building pavements in slabs about 10 feet wide has developed naturally and has resulted in effective control of longitudinal cracking.

During the early part of this decade researches such as the test road at Pittsburg, Calif., the Bates road tests in Illinois, and experiments of the Bureau of Public Roads at Arlington, Va., developed certain basic facts concerning the effect of loads on pavement slabs of various designs. In all of these researches the need for strengthening slab edges was definitely indicated. Free edges of slabs can be strengthened most simply by increasing the slab depth, but where the slab adjoins others the possibility for inter-slab support as a means

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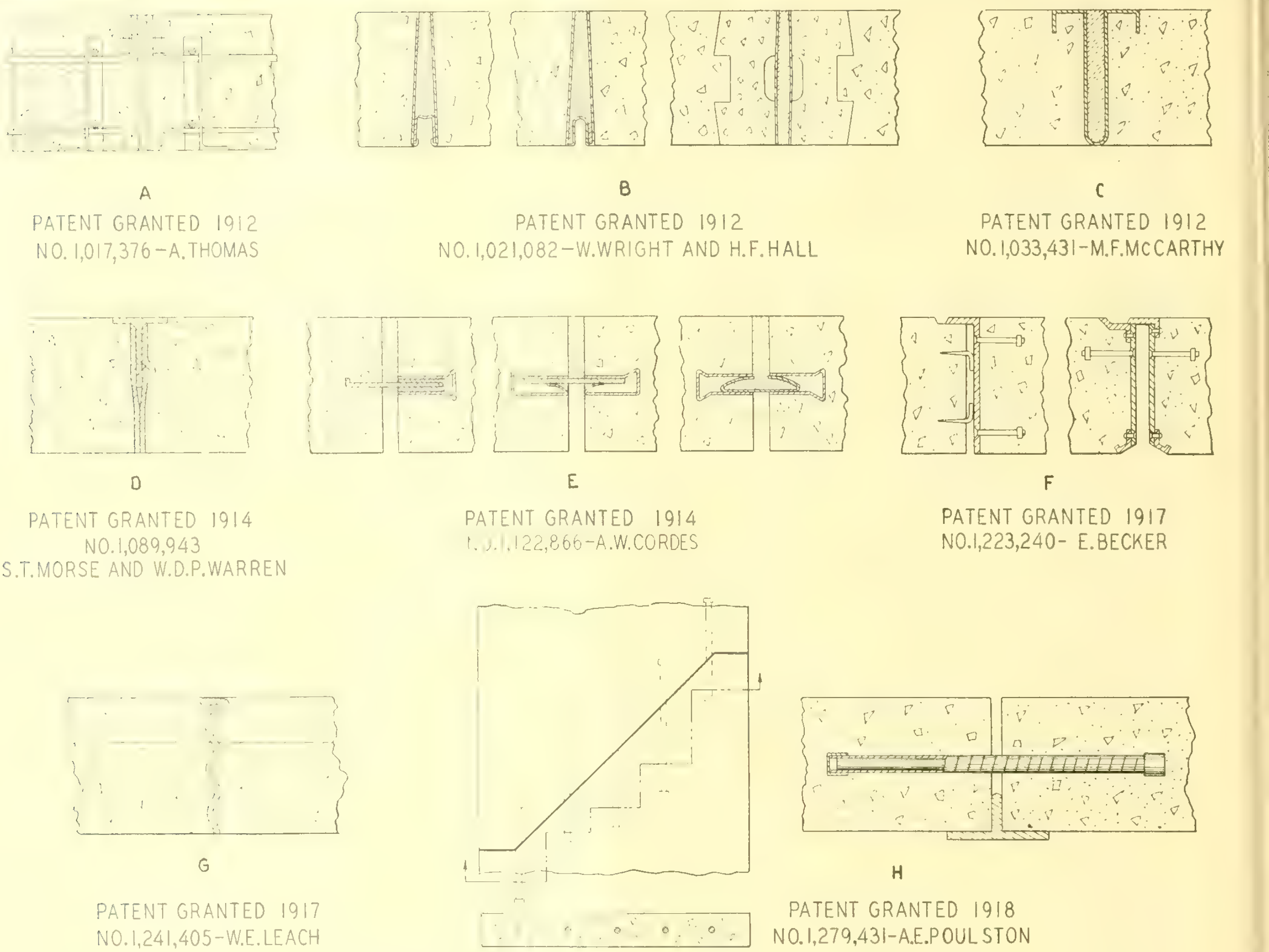
[10] Engineering News-Record, vol. 88, no. 9, Mar. 2, 1922, pp. 357–8.

[11] Engineering News-Record, vol. 85, no. 7, Aug. 12, 1920, p. 305.



A PATENT GRANTED 1912 NO. 1,017,376-A.THOMAS

B PATENT GRANTED 1912 NO. 1,021,082-W.WRIGHT AND H.F.HALL

C PATENT GRANTED 1912 NO. 1,033,431-M.F.McCARTHY

D PATENT GRANTED 1914 NO. 1,089,943 S.T.MORSE AND W.D.P.WARREN

E PATENT GRANTED 1914 NO. 1,122,866-A.W.CORDES

F PATENT GRANTED 1917 NO. 1,223,240- E.BECKER

G PATENT GRANTED 1917 NO. 1,241,405-W.E.LEACH

H PATENT GRANTED 1918 NO. 1,279,431-A.E.POULSTON

Figure 3.—Some Joint Designs That Were Patented in the United States Between 1910 and 1919.

for strengthening the edges has long been recognized and has led to many proposals for joint designs in which varying degrees of interlocking action are developed. The use of transverse joint designs in which some form of load-transfer mechanism is incorporated has become quite general, the round, steel dowel bar being the most common.

Efforts were also made to strengthen structurally, by systems of steel reinforcement, certain parts of the slab, usually the edges and corners. Some of these proposed systems were very simple; others were quite extensive and complicated.

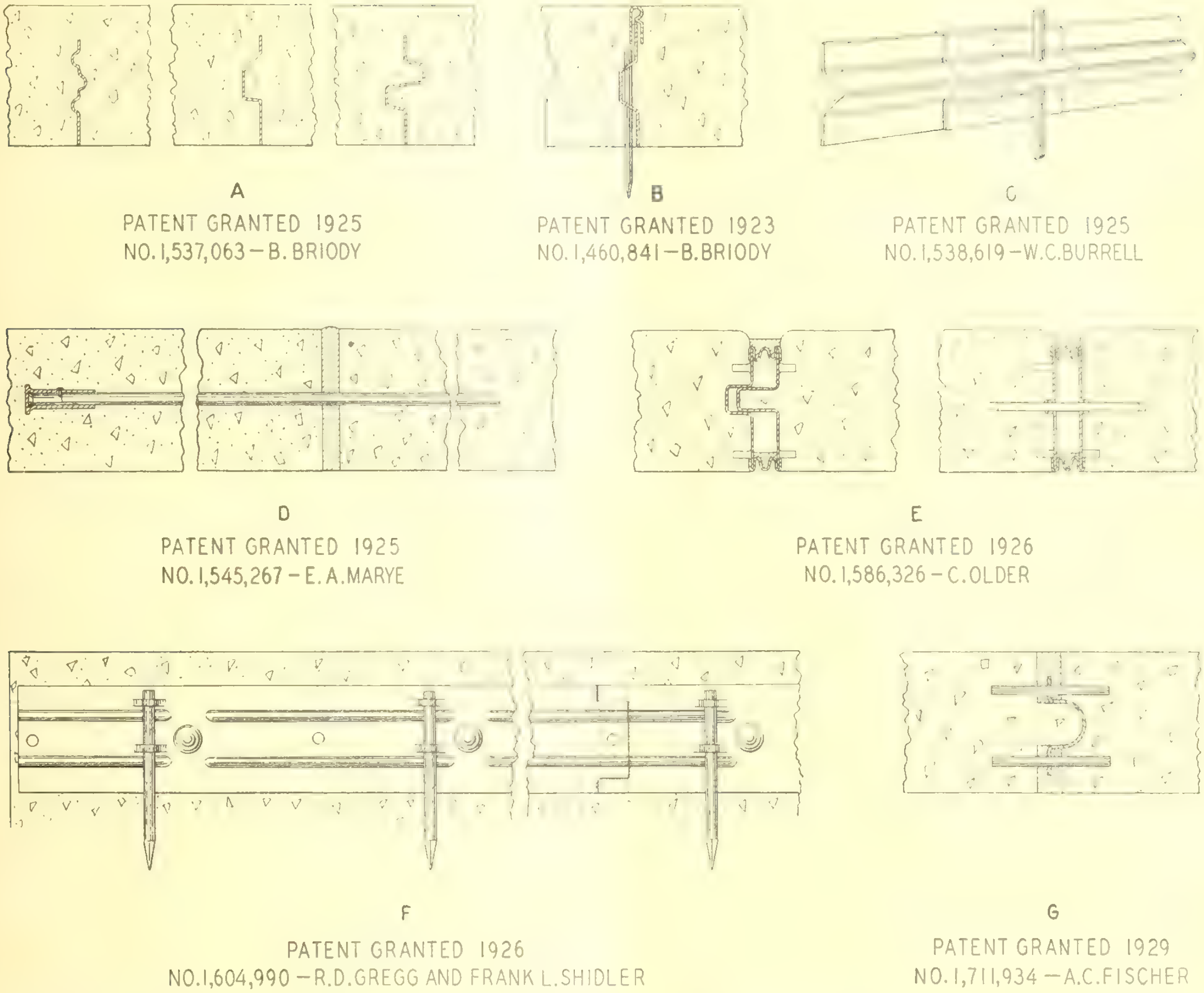
In figure 4 are shown a number of typical joint designs for which patents were granted between 1919 and 1929. It is of interest to compare this group with that shown in figure 3 and note how the changes in ideas about joint design that have just been discussed are reflected in these two groups of designs. The idea of edge protection disappears and the idea of load transfer appears as the most important factor in the design.

Figure 4–A shows a method for the control of cracking by means of a transverse, steel parting strip so deformed as to create corrugations of various shapes to provide for an interlocking action of the two slab edges. Figure 4–B is similar except that complete separation is provided without cracking and a single approximately rectangular tongue and groove is formed. Figure 4–C shows a deformed metal plate intended for longitudinal joints and forming a triangular tongue and groove similar to that used in one of the test sections. Figure 4–D shows a doweled joint with a short cap to provide for end freedom of the dowel during expansion. In figure 4–E are shown several designs incorporating various methods of load transfer together with a collapsible metal box intended to form the opening between the slabs at the time of construction and to remain in place as a seal afterward.

The use on one slab of rounded projections that engage sockets of the same shape on the adjoining slab is proposed for load transfer in the longitudinal joint shown in figure 4–F. The use of bonded dowels is contemplated in this design. Figure 4–G shows an expansion joint in which inter-slab action is obtained by both a concrete tongue and groove and by steel bars which pass from slab to slab.

CLOSER SPACING OF TRANSVERSE JOINTS GRADUALLY ADOPTED

The great differences of opinion as to how far apart joints should be placed, which were remarked in the 1915 editorial, persisted for many years. In 1931 three States used expansion joints only at bridge approaches while several others employed them only under special conditions (which frequently meant only at bridge approaches). The remainder, with the exception of one State, installed expansion joints at intervals o



A
PATENT GRANTED 1925
NO. 1,537,063 — B. BRIODY

B
PATENT GRANTED 1923
NO. 1,460,841 — B. BRIODY

C
PATENT GRANTED 1925
NO. 1,538,619 — W. C. BURRELL

D
PATENT GRANTED 1925
NO. 1,545,267 — E. A. MARYE

E
PATENT GRANTED 1926
NO. 1,586,326 — C. OLDER

F
PATENT GRANTED 1926
NO. 1,604,990 — R. D. GREGG AND FRANK L. SHIDLER

G
PATENT GRANTED 1929
NO. 1,711,934 — A. C. FISCHER

Figure 4.—Some Joint Designs That Were Patented in the United States Between 1919 and 1929.

approximately 100 feet or less. This one State constructed a 4-inch expansion joint at approximately 800-foot intervals and used no other transverse joints in concrete pavements.

By 1934 all of the States, with but one exception, were installing expansion joints at intervals of 100 feet or less (and in this one the interval used was 150 feet). Also, the adoption by many States of the policy of using contraction joints between the expansion joints resulted in a still further reduction of the interval between transverse joints. During the early part of 1934 the Bureau of Public Roads made the requirement that on Federal-aid road construction expansion joints should be provided at intervals of not more than 100 feet and that in plain-concrete slabs transverse joints should be placed at intervals not exceeding 30 feet. It was required also that the width of expansion joints should be not less than three-fourths nor more than 1 inch and that some provision for load transfer should be made in all transverse joint installations. These requirements for Federal-aid construction have probably accelerated the trend toward a shorter distance between joints, a trend that has been discernible for a number of years in spite of the wide variation of opinion which has existed.

Although there is widespread acceptance of the desirability of inter-slab load support at transverse joints, there is both a wide divergence of opinion as to how it should be accomplished and a decided lack of agreement on the fundamental structural requirements of a satisfactory joint design. This condition is caused principally by a lack of conclusive evidence from tests or other sources as to what these requirements should be.

In 1927 Westergaard published an analytical treatment of the action of a doweled joint under load.[12] This valuable contribution to the general subject of joint design has apparently not been given the attention it deserves. The analysis showed the effect of dowel spacing on the stresses directly under a load acting at a doweled edge of a pavement slab, throwing new light on the critical stresses in the vicinity of joints of this type. It is indicated that dowels, even under the ideal conditions that were assumed, must be placed very close together if they are to be reasonably effective as a means for transferring load.

Aside from Westergaard's analysis there has been little information available except for occasional reports of the observed service behavior of certain joint installations.

An examination of the designs shown in figure 5 will reveal how widely opinions vary as to what is required structurally in joint action. It will be noted that some believe that a joint should be shear resistant

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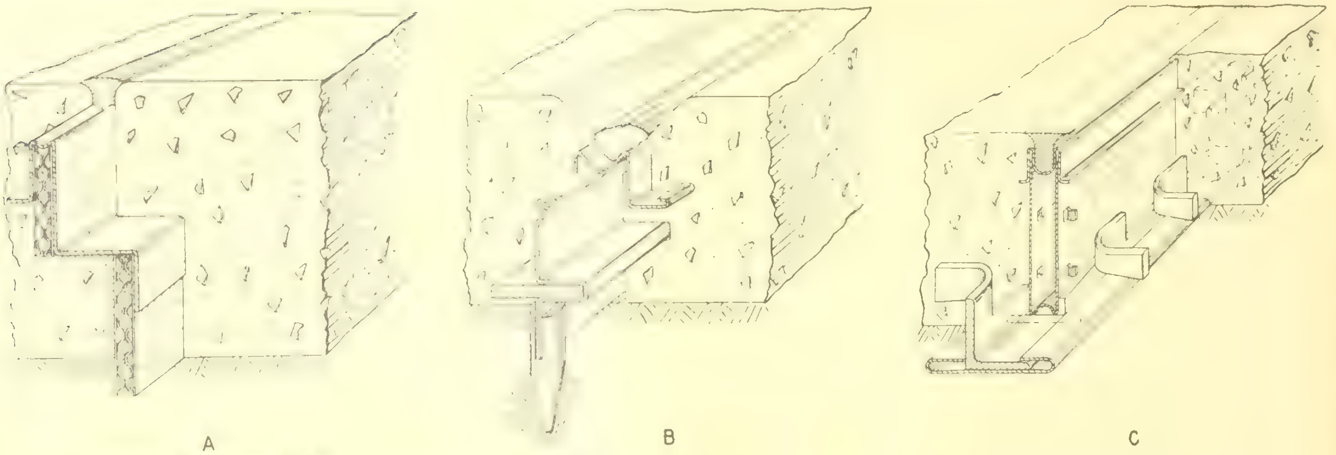
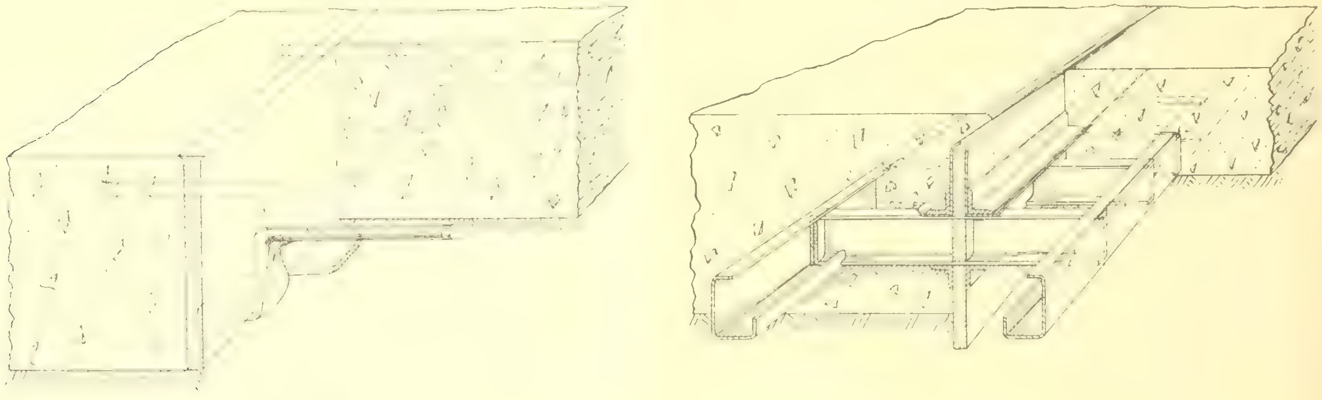
[12] Analysis of Stresses in Concrete Roads Caused by Variations of Temperature. Public Roads, vol. 8, no. 3, May 1927.



A
PATENT GRANTED 1932
NO. 1,884,647 – R.B.GAGE

B
PATENT GRANTED 1932
NO. 1,856,722 – C. OLDER

C
PATENT GRANTED 1934
NO. 1,956,809 – R.R.ROBERTSON



D
NEW YORK STATE STEP PLATE DESIGN

E
NEW JERSEY CHANNEL DOWEL DESIGN

Figure 5.—Joint Designs That Typify Various Opinions as to What Is Required Structurally in Joint Action.

but should be without stiffness so far as vertically applied loads are concerned. Others are equally convinced that an effort should be made in designing the joint to develop the same resistance to bending at the joint as is found in the interior of the slab.

Figure 5–A shows a design in which no effort is made to develop bending resistance in the joint structure itself. If the load approaches the joint from one direction there is direct transfer to the adjacent slab through the reaction developed on the ledge or shelf on the adjacent slab. The joint in this case acts somewhat as a free hinge. If the load approaches from the opposite direction there can be no transfer of load.

One of the designs, shown in figure 5–B, shows a steel plate running the length of the joint and fitting into grooves or recesses formed into the two opposing slab ends. The plate acts as a key or spline and by its stiffness transfers part of the load across the joint. The flexibility of the plate permits a certain amount of hinge action to occur. Figure 5–C shows another design in which one slab rests on a shelf on a slab opposite. The shelf or ledge in this case is of steel and is anchored into the concrete of the slab end. In order to obtain the same support for each slab, the shelf angles are cut into short sections, half of the projections extending from each slab and so staggered that they intermesh, giving a typical hinge construction.

Another joint identical in principle but differing in the details of its design is that being used in New York State and shown in figure 5–D. In this case the shelves are individual castings anchored into concrete as shown. In neither of these is there any attempt to develop resistance to bending in the joint structure.

A design differing radically in principle is that used by the State of New Jersey and shown in figure 5–E. The theory behind this design is that the same resistance to bending should be provided at the joint as is found at the other points along the slab, and the series of stiff members which span the joint in this design are for this purpose.

JOINTS MAY ACT TO RELIEVE STRESSES RESULTING FROM EXPANSION, CONTRACTION, OR WARPING

A feature of joint design that has given considerable concern and that has been and is still being given a great deal of study is the filling and sealing of expansion joints. It presents a related but separate problem and was not a part of the investigation that is being reported in this series of papers.

In this brief review it has been noted that joints appeared with the first use of concrete for paving, probably the division of the early pavements into small units being as much for convenience in construction as for any other reason. Later, expansion joints as such appeared with the expressed idea that their use would control the cracking which inevitably occurred. Difficulty in the construction of joints and their apparent ineffectiveness as a means of crack control led to a reaction that resulted in a decreased use of joints for a period. The results obtained by this policy were not altogether satisfactory, however, and the continued urge for smoother and better appearing pavements led to the introduction of what have been called contraction joints placed between expansion joints, the length of the slab units being gradually decreased. Load transfer as a recognized factor in joint design appeared after the World War and is now quite generally considered to be an essential requirement.

The importance of freely acting joints as a means for the relief of stresses developed by restrained temperature (and possibly moisture) warping is as yet not generally appreciated, although the results obtained with the longitudinal center joint have been evident for years and both the theoretical and experimental indications of the importance of warping stresses were pointed out before the Highway Research Board nearly a decade ago.[13] [14]

As shown in the preceding papers of this series, the present investigation has developed a considerable amount of information about the magnitude and the distribution of warping stresses. This information, much of which is new, emphasizes the necessity for controlling these stresses in concrete pavements if adequate wheel-load resistance is to be provided. The data that have been presented relative to warping stresses bear directly, therefore, on one important function that a joint should be designed to perform.

Thus it appears that joints in concrete pavements may be classified according to their intended function, as follows:

1. Those designed to provide space in which unrestrained expansion can occur.
2. Those designed for the relief or control of the direct tensile stresses caused by restrained contraction.
3. Those designed to permit warping to occur, thus reducing restraint and controlling the magnitude of the bending stresses developed by restrained warping.

Obviously a joint may and frequently does perform all three of these functions. An expansion joint, for example, may permit unrestrained expansion, contraction, and warping, while a joint of the so-called contraction type may actually benefit the pavement more by its ability to relieve warping stresses than by its intended function of relieving direct tensile stresses caused by contraction.

It should be kept in mind that joints are needed in concrete pavements for the one purpose of reducing as much as possible the stresses resulting from causes other than applied loads in order that the natural stress resistance of the pavement may be conserved to the greatest possible extent for carrying the loads of traffic.

A joint is potentially a point of structural weakness and may limit the load-carrying capacity of the entire pavement so that it is important to examine joint designs from this standpoint as well as for their ability to permit unrestrained expansion, contraction, and warping.

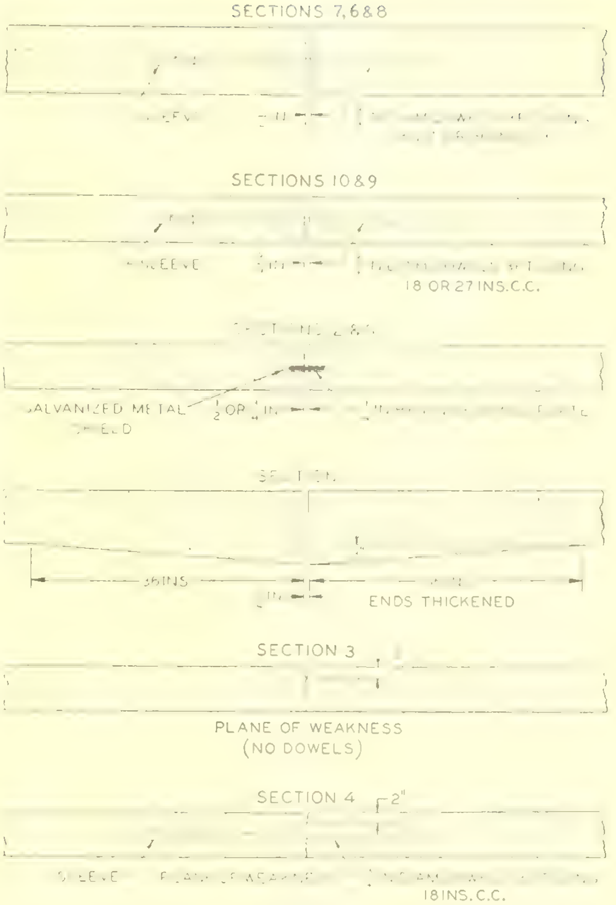


Figure 6.—Designs of Transverse Joints Included in the Investigation. The Bond was Destroyed on all Dowels Across Transverse Joints by Painting and Greasing.

In studying the structural action of joints in this investigation, each joint was subjected to tests to determine its relative effectiveness for:

1. Permitting unrestrained expansion and contraction.
2. Permitting unrestrained warping at the joint.
3. Reducing the structural weakness created by the break in the slab continuity at the joint.

INSTALLATION AND DETAILS OF TRANSVERSE JOINTS DESCRIBED

In the first paper of this series there was given a brief description of the 10 transverse and the 10 longitudinal joints that were included in the pavement sections built for this investigation. Before beginning the description of the tests and the discussion of the results, it is desirable to refer again to the details of these joints.

The details of the several types of transverse joints studied are shown in figure 6. The joints are all classed as expansion and contraction joints with the exception of the two transverse plane-of-weakness or dummy joints that were incorporated in sections 3 and 4. These two are primarily contraction joints. The transverse joints are divided into four groups, according to type.

The first group comprises the dowelled expansion and contraction joints found in sections 6, 7, 8, 9, and 10. In this group the dowels were round, rolled-steel bars three-fourths inch in diameter and 3 feet in length in all cases but both the spacing of the dowels and the distance between the abutting slab ends (or joint opening) were varied, as shown in table 1, in order to determine the

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[13] Analysis of Stresses in Concrete Pavements Due to Variations of Temperature, by H. M. Westergaard, Proceedings, Sixth Annual Meeting, Highway Research Board, December 1926, pp. 201–215.

[14] Progress Report on the Experimental Curing Slabs at Arlington, Virginia, by J. T. Pauls, Proceedings, Sixth Annual Meeting, Highway Research Board, December 1926, pp. 192–201.

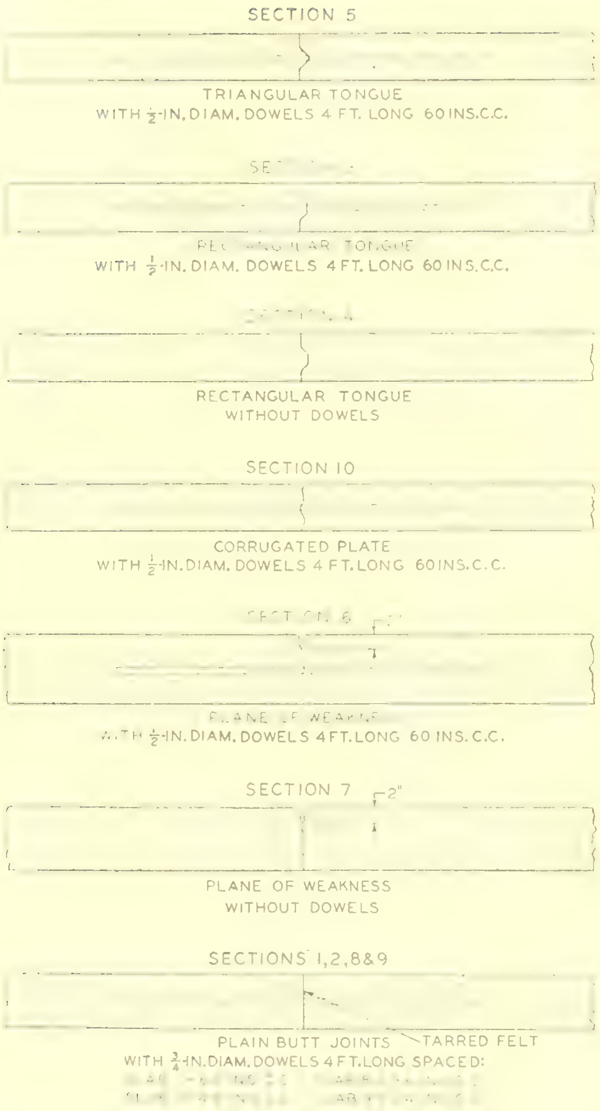


Figure 7.—Designs of Longitudinal Joints Included in the Investigation. All Dowels (or Deformed Tie Bars) Were Bonded Throughout Their Length.

effect of these variables on the structural action and general efficiency of joints of this type.

Table 1.—*Details of doweled expansion and contraction joints*

Section no.	Joint opening	Dowel spacing
	Inch	*Inches*
6	½	27
7	½	18
8	½	36
9	¾	27
10	¾	18

At the time of installation the dowels were carefully painted and coated with grease to prevent bonding with the concrete, and special pains were taken to insure that all of the dowels were parallel to the subgrade and to the longitudinal axis of the pavement section. As will be noted in the drawings (fig. 6) a short cap or sleeve on one end of each dowel permits free longitudinal movement of the dowel within the concrete.

In the second group of transverse joints are the two plate-dowel designs found in sections 2 and 5, the only difference between the two being in the width of the joint opening. In each the steel dowel plate is one-fourth by 4 inches in section and is continuous for the full 10-foot width of the pavement slab. The bonding of the dowel plates to the concrete was prevented by an encasing shield of sheet metal which extends beyond the edges of the dowel plate in such a manner as to provide for free movement of the dowel plate during expansion and contraction of the pavement. The widths of the joint openings employed in these two joints are one-half inch (sec. 2) and three-fourths inch (sec. 5).

The third type of transverse joint is that in which the thickness of the slab ends abutting the joint has been increased above the thickness of the interior of the slab for the purpose of strengthening the transverse slab edges. In this design no load transfer is attempted since no inter-support is necessary; hence there is no direct connection between adjacent slabs. Such a joint was placed in section 1. The ends of this section at the open joints were also thickened.

The fourth and last type of transverse joint included in this investigation is the weakened-plane or dummy joint found in sections 3 and 4. These transverse joints were constructed in the same manner as the longitudinal joint of the same type except that bonding of the dowels was prevented in one (section 4), while in the other (section 3) all dowels were omitted. The spacing of the dowels in section 4 is 18 inches.

INSTALLATION AND DETAILS OF LONGITUDINAL JOINTS DESCRIBED

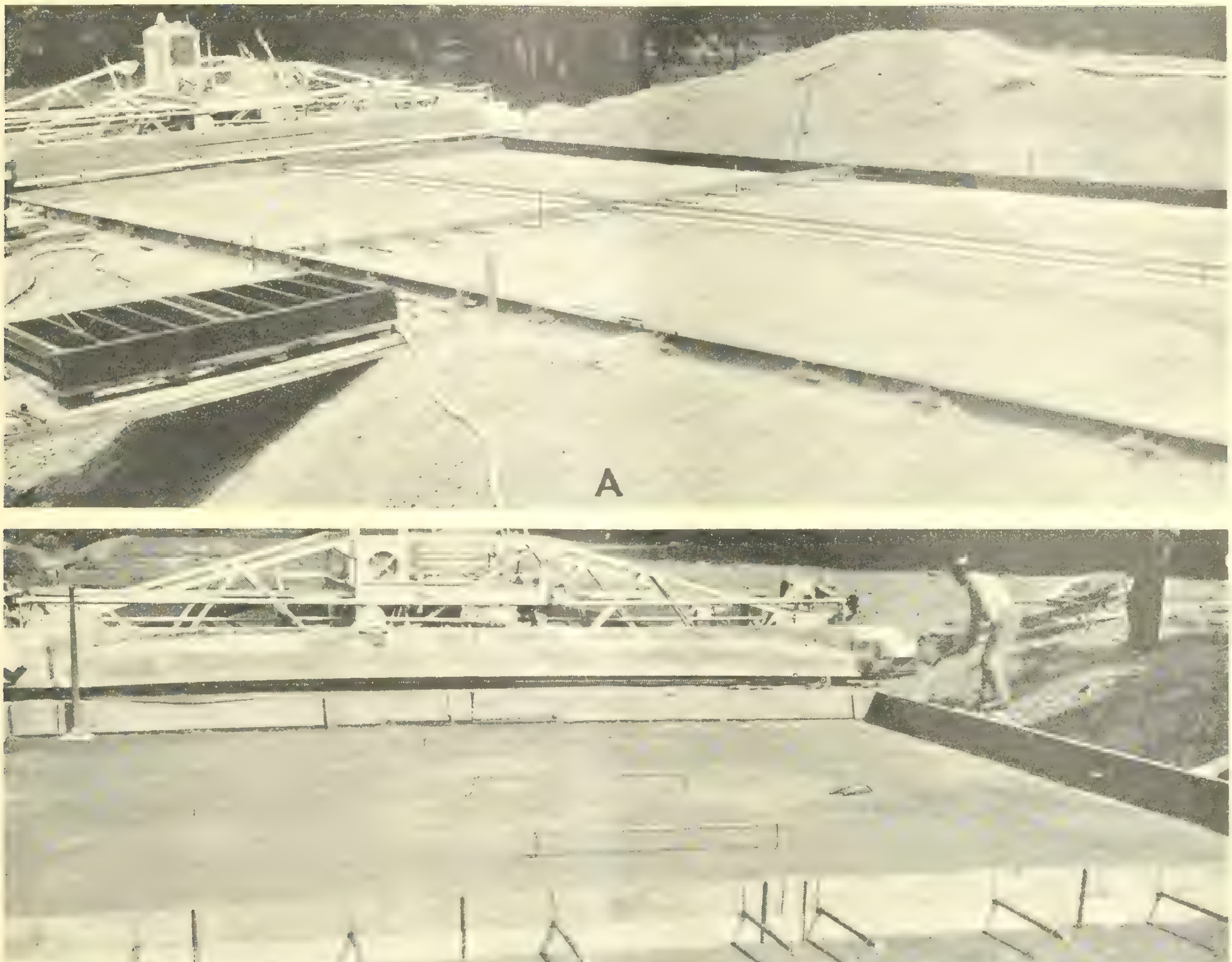
Details of the designs of the 10 longitudinal joints are shown in figure 7. With the exception of those found in sections 4 and 7, where no steel crosses the joint and free contraction is permitted, all of the designs are primarily warping joints.

By definition a dowel may or may not be bonded to the two pieces which it joins. In woodworking practice, dowels are more often bonded than not. In concrete pavement construction the dowels that cross the longitudinal joint are nearly always bonded to the concrete and are usually called tie-bars, although they are more exactly described as dowels in bond when they are called upon to withstand shearing forces. In this report the steel bars used for joining two abutting slab edges are generally referred to as dowels if the bond has been broken and dowels in bond if the bond still exists.

The longitudinal joint designs included in this investigation can also be grouped according to type.

The first group consists of four sections (sections 5, 3, 4, and 10) in which a tongue-and-groove construction was obtained by casting the concrete around a preformed, steel joint plate. The rectangular- and triangular-shaped tongue and groove and the sinusoidal tongue and groove (sections 3, 5, and 10, respectively) are held together with dowel bars in bond at 60-inch intervals.

In the second group are the longitudinal plane-of-weakness or dummy joints in which the surface of the slab was grooved to a depth of approximately one-third of the slab thickness at the time of construction, it being intended that an irregular fracture would subsequently develop extending from the bottom of the groove downward to the bottom of the slab. One of these sections (section 6) has dowel bars in bond placed



Longitudinal and Transverse Joints in Place Ready for the Concrete to Be Cast. A, Corrugated Metal Plate Used to Form the Longitudinal Joint in Section 10. B, Dowels in Place for a Doweled Transverse Joint and for a Longitudinal Weakened-Plane Joint With Dowel Bars in Bond. The Wooden Header Was Left in Place Until the Concrete Had Hardened and Was Then Removed. C, Rectangular Tongue-and-Groove Longitudinal Joint.

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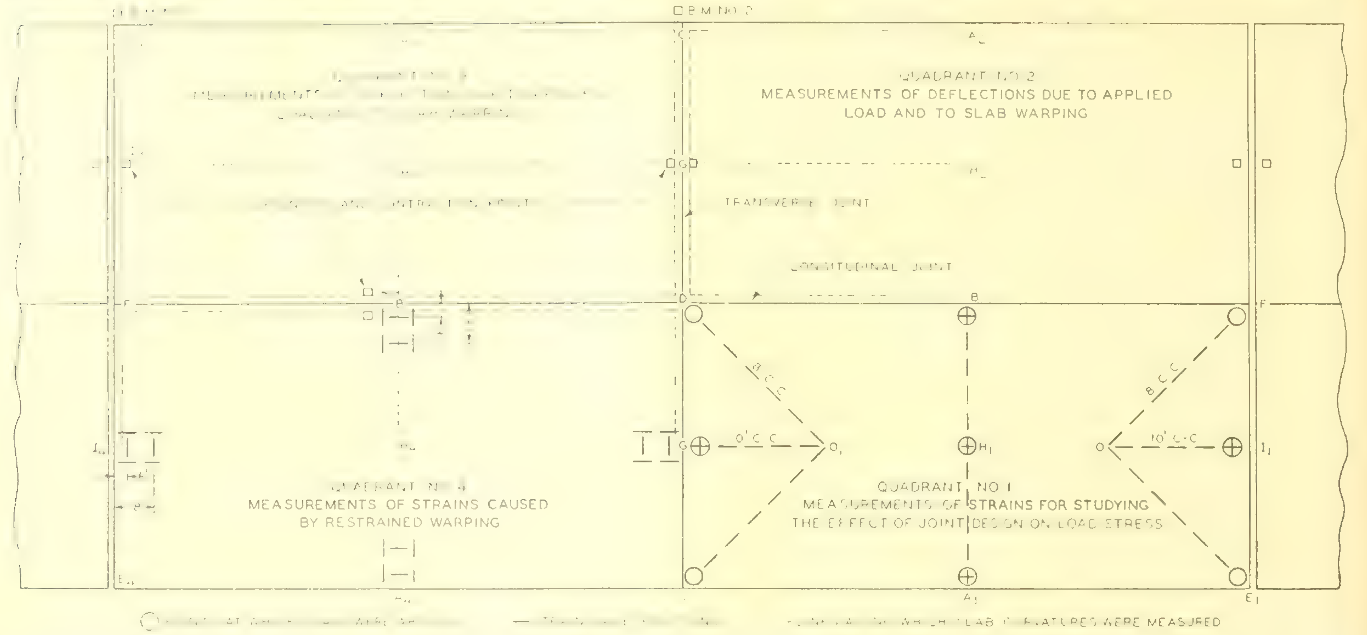
QUADRANT NO 2
MEASUREMENTS OF DEFLECTIONS DUE TO APPLIED LOAD AND TO SLAB WARPING
TRANSVERSE JOINT
LONGITUDINAL JOINT
B
10' C-C
H1
QUADRANT NO 4
MEASUREMENTS OF STRAINS CAUSED BY RESTRAINED WARPING
QUADRANT NO 1
MEASUREMENTS OF STRAINS FOR STUDYING THE EFFECT OF JOINT DESIGN ON LOAD STRESS
A1
E1
POINTS AT WHICH SLAB CURVATURES WERE MEASURED

Figure 8.—Plan of a 20 by 40-Foot Test Section Showing the Positions of the Applied Loads and of the Measuring Instruments for the Study of Joint Behavior. Measurements of Deflections in Quadrants 2 and 3 Were Made With Loads Applied to Quadrant 3 at Load Positions Corresponding to Those Indicated by Circles in Quadrant 1.

across the joint at 60-inch intervals, while in the other (section 7) no dowels were used.

The third group embraces four sections (sections 1, 2, 8, and 9) in which the vertical faces of the abutting edges of the two 10-foot slabs were separated by a single thickness of tarred felt but held together by dowels in bond. These dowels were deformed bars of steel ¾ inch in diameter and 4 feet in length. They were spaced at intervals of 60, 48, 36, and 24 inches, respectively, in the four sections listed above.

As stated previously, in making the study of the structural behavior of these joint designs, tests were made on each to determine:

1. How freely expansion and contraction occurred.
2. To what degree unrestrained warping of the slab edges was permitted.
3. Their relative effectiveness in reducing the natural weakness of the joint edge by transferring load or by other means.

Measurements of expansion and contraction, of slab shape, and of slab deflection and strain under load were necessary to make these determinations. The location of the points at which the various measurements were made are shown on the plan of one of the test sections in figure 8. In this figure a letter is assigned to a definite point on a test slab while the subscript indicates the quadrant number. For example, the letter "E" is assigned to the free corner, and "H" the center point of the test panel and the subscripts 1, 2, 3, and 4 indicate the four quadrants of the test section. As in earlier descriptions, the various tests are described as having been made on the different quadrants of the test section for the sake of clarity in presentation. Actually certain tests were frequently made on more than one quadrant of a given test section.

SCHEDULE OF DEFLECTION AND STRAIN MEASUREMENTS OUTLINED

The points at which the expansion and contraction of the slab as a whole were measured are shown in the free ends and at the transverse joint in quadrants 2 and 3. The measurements were made with the specially constructed micrometer described in the first report of this series, the normal distance between the gage points being approximately 7 inches. The movements at the transverse test joint were compared with those at a joint which was known to be free to expand and contract and this comparison served as a basis for estimating the relative restraint offered by the various designs to longitudinal slab movements. These measurements covered both the daily and annual cycles of changes in slab length.

The study of the annual variations was made from measurements made twice daily over a period of about 2 years. The measurements were made at about 9 a. m. and about 3.30 p. m.

In the study of the daily variation in slab lengths, measurements were made on selected days at 2-hour intervals for a complete 24-hour period. The days were selected so as to give as wide a temperature range as possible for the particular season of the year.

From the data obtained it is possible to estimate very closely the extent of both of these cycles of change in slab length and joint width.

The relative restraint to free warping developed by the various joints was determined by comparing the magnitude of the deflection at the joint in question with that at a free edge under a given temperature condition and also by comparing the strains resulting from warping restraint at corresponding points at the free edge and at the joint under test. The shape of the deflected slab was determined with the clinometer and the movements of the extreme corners of the slabs were also measured with micrometer dials on fixed supports. The tests were usually started very early in the morning and readings were taken at 1-hour intervals until the maximum warping in each direction had occurred. In making the comparison for a transverse joint, deflections at the free corner (point E) were compared with those at the transverse joint corner (point C). For a longitudinal joint the deflections at the free corner (point E) were compared with those at a longitudinal joint corner (point F).

The lines along which the clinometer points were installed for the warping studies are shown in the third quadrant of figure 8. The restraint to warping offered by a transverse joint was indicated by a comparison of the curvature along the line E_3—A_3 with that along the line C_3—A_3. For the same study of the longitudinal joint action the curvature along the line E_3—I_3 was compared with that along the line F_3—I_3.

In measuring the curvature with the clinometer two sets of readings were made for each comparison, the first in the early morning at a time when the upper surface of the pavement was at a lower temperature than the lower surface and a second set in the early afternoon when the temperature of the upper surface of the slab was above that of the lower surface.

Since any tendency of the joint to restrain the slab edge from warping freely would be reflected by an increase in the magnitude of the warping stresses, a comparison was made in each case between the warping stresses at a free edge and those at the joint in question. The method of arriving at the values of the warping stresses from measured strains was described in part 2 of this series of reports. The location of the strain gages for these comparisons is shown in the fourth quadrant of the test section in figure 8. In the study of the transverse joint the stresses indicated by the group of gages at I_4 were compared with those measured by corresponding gages at G_4. Similarly, for the study of the longitudinal joint the stresses indicated by the group of gages at A_4 were compared with those found at the corresponding positions at point B_4.

As remarked before, every joint is potentially a structural weak spot and some means for strengthening this part of the slab is usually a part of the joint design. The common method is by transferring part of the load to the adjoining slab through the shear resistance of the joint. In this investigation the relative effectiveness of the various joints from the standpoint of their ability to strengthen the slab edge was determined by comparing the critical strains and deflections caused by a load acting near a joint edge with those produced by the same load at other points on the slab.

Loads were applied at the four corner points C, D, E, and F (fig. 8) to determine how effectively the joint functioned in reducing the critical deformations caused by a load acting at the corner of the slab. Similarly, the effectiveness of the design under the action of loads applied at the joint edge (but away from the slab corner) was determined from data obtained with loads applied at points A, B, G, I, and H. The lines along which the curvature of the slab was measured under the action of the applied loads are shown in the second, third, and fourth quadrants, while the strain-gage locations that were used in this part of the study are shown in the first quadrant of this figure. The detailed schedule of the deflection measurements follows:

CORNER TEST

Load applied at point:	Deflection measured along line:
E_3.	E_3—A_3 and E_3—F_3.
C_3.	A_3—A_2 and C_3—D_3.
F_3.	E_3—I_4.
D_3.	D_3—B_3.
EDGE TEST	
A_3.	A_3—B_3.
B_3.	A_3—H_4.
I_3.	I_3—H_3.
G_3.	H_3—H_2.

For each test the shape of the unloaded slab was determined, the load was applied and the shape of the loaded slab measured, the change in shape being taken as the deflection caused by loading.

CRITERION OF JOINT EFFICIENCY ADOPTED

A somewhat similar schedule was followed in making the strain measurements. For the load applied at the slab corners the strains were measured in the upper surface of the slab along the bisector of the corner angle. For example, with a load applied at point E_1 the strains were measured along the line E_1—O_1 and similarly for the other corners of the slab.

For loads acting at the edge points the strains were measured both parallel and perpendicular to the slab edge at the point of load application and for a sufficient distance along a line perpendicular to the edge to insure the finding of the critical tensile stress in the upper surface of the slab. For example, with a load acting at point A_1 the strains were measured in both directions directly under the load and along the line A_1—H_1.

Loads were applied at point H solely for the purpose of obtaining a comparison of the critical stresses caused by a load at this point with those caused by the same load applied at certain other points. Since the critical stresses occur directly under the load in the case of a load acting in the interior of the slab, only the strains developed in the upper surface directly under the load were measured. These strains at point H were measured in both the longitudinal and transverse directions.

Before making a comparison of the relative effectiveness of various joints for accomplishing any certain purpose, it is necessary to establish some rational basis of comparison. If it is desired to compare joints on the basis of their ability to reduce the deflection of the slab edge at some particular point, then deflection measurements at that point may be used as a means for estimating the effectiveness of the joint. However, if the purpose of the joint design is to reduce the stresses from applied loads so as to, in effect, increase the load-carrying capacity of the edge of the slab, then it is necessary to arrive at the basis of comparison through the measurements of strains and not deflections, for it has been clearly demonstrated in these tests that the precision of the deflection data is not sufficient to warrant any conclusions relative to attendant stress conditions. The question then arises as to how stresses determined from strain measurements may best be used as a basis for judging the relative structural effectiveness of various joint designs.

It has been established that if a given load is applied at various points on the surface of a concrete pavement slab of uniform thickness the critical stress will be a minimum when the load is applied at an interior point and that the critical stress will reach its maximum value when the load is applied at the free edge.

If a joint operated with a maximum amount of structural efficiency, it would reduce the critical load stress at the joint edge to a value equal to that found in the interior of the slab. If, on the other hand, it was completely ineffective the critical stress for a load at the joint would equal the critical stress for the same load acting at a free edge.

These two values therefore, delimit the range of joint efficiency so far as the ability to reduce load stresses is concerned and suggest a stress formula which will furnish a rational measure of joint efficiency.

If, for a given applied load on a slab of uniform thickness,

σ_j is the critical stress for the load applied at the joint edge,

σ_f is the critical stress for the load applied at the free edge,

and σ_i is the critical stress for the load applied at an interior point.

Then the joint efficiency, *E*, may be expressed as follows:

$$E=\frac{\sigma_f-\sigma_j}{\sigma_f-\sigma_i}$$

In other words, the reduction in edge stress accomplished by the joint under consideration is compared to that accomplished by the complete continuity of the interior condition, as a measure of efficiency.

In making the stress determinations upon which the joint efficiency values were based, it was not considered desirable to depend entirely upon stress values obtained at a single point no matter how well established the value might be.

For the determination at each load point, therefore, eight tests were made, each at a somewhat different location. For example, to establish a stress value for the free edge (point A) eight tests were made altogether, and in no two was the bearing plate in the same spot on the same quadrant of the test section, although in all cases it was at the free edge and close to the midpoint of the slab length.

Tests were made also at all of the longitudinal joint corners on the four constant-thickness slabs but were not made at these corners on the thickened-edge slabs because there would be no basis for comparing strains measured at corners of different thicknesses.

Deflection and strain data that indicate the strengthening effect of thickened edges at slab corners appear later in this report.

DATA ON VARIATIONS IN JOINT WIDTH PRESENTED

The annual variation in the widths of the various transverse joint openings is indicated by the data shown in figure 9 in which the ordinates are the variations in the measured joint width when compared to a set of initial measurements made in November 1930, shortly after the pavement was constructed. The morning measurements were made between 9 and 9:30 and the afternoon measurements between 3:30 and 4 o'clock.

The joint designations used in this figure are as follows: The transverse joint in the center of the test section is given the same number as the test section in which it is located. For example, joint 3–3 refers to the transverse joint across the center of test section 3. The open joint between two adjoining test sections is given the numbers of the two sections between which it is found, as for example, joint 2–3 is the open joint between test sections 2 and 3. It will be recalled that these open joints between the test sections were all 2 inches wide and were kept open, preventing any connection between the slab ends.

It was mentioned earlier that the expansion and contraction measurements were of necessity made at the level of the upper surface of the pavement. The observed horizontal movements were therefore the results of the direct expansion and contraction of the slab combined algebraically with the horizontal component (at the plane of the measurements) of any tilting of the slab ends caused by warping. To determine the changes in joint width caused solely by expansion or contraction of the slab, it is necessary to correct the observed changes for the effect of the warping present at the time of observation.

Figure 9 shows the seasonal variations in observed joint width. The correction for warping mentioned in the preceding paragraph is considerably more important in a consideration of the daily variations than it is when seasonal changes are involved for the following reasons:

The afternoon observations were made at the time of maximum downward warping of the slab edges. During the summer when the pavement was expanded to its greatest length the slab edges were warped upward by moisture conditions within the slab to the maximum degree. Data were presented in the second report of this series to show the relative degrees of the daily and seasonal warping found in the test sections at different seasons of the year. The data presented in that report on the effect of seasonal moisture changes indicated that the moisture condition was rather unstable during the summer months. This resulted from abnormal weather conditions during the summer of the year in which the observations were made. Moisture warping observations that have been made since that report was written and the data showing the change in length of the pavement caused by moisture changes both indicated that, under normal summer weather conditions, the moisture state of the pavement is quite stable during the summer months.

It is indicated by the data just mentioned that the downward warping of the slab edges on critical days during the summer at the time of the afternoon observations is approximately equal to the upward warping caused by the seasonal change in its moisture condition. This conclusion is based upon the assumption that all of the seasonal moisture warping is upward; in other words, that there is at no time more moisture in the pores of the concrete in the upper part of the pavement slab than is present in those near the subgrade. This assumption seems to be supported by all of the data available from these tests.

It appears therefore that, at the time the measurements indicating the maximum closing of the joints were made, the slabs were probably in nearly a flat condition. For the morning observations in winter all evidence indicates little warping from either moisture or temperature. If these assumptions are correct, data such as are shown in figure 9 indicate the seasonal variations in the widths of the joints with sufficient accuracy without corrections for the effects of warping. The indicated daily variations in joint width are not true measures of expansion and contraction and should not be used without correction. The method used for determining the magnitude of the warping correction is described a little farther on in this report in connection with the discussion of daily variations in joint width.

SLABS DID NOT EXPAND AND CONTRACT SYMMETRICALLY

If a comparison is made between the annual variations in width of the several joints, it will be observed that the movements at the joints formed by the free ends of the slabs are, in general, greater than those at the regular transverse joints. The observed difference between the opening of the transverse test joints and that of the open joints between the test sections indicates that the resistance of the former to expansion and contraction movements causes either a deformation that alters the length of the slab or a shifting of the center of the slab panel longitudinally over the subgrade.

That there is no appreciable stress deformation that changes the slab length is shown by the numerous

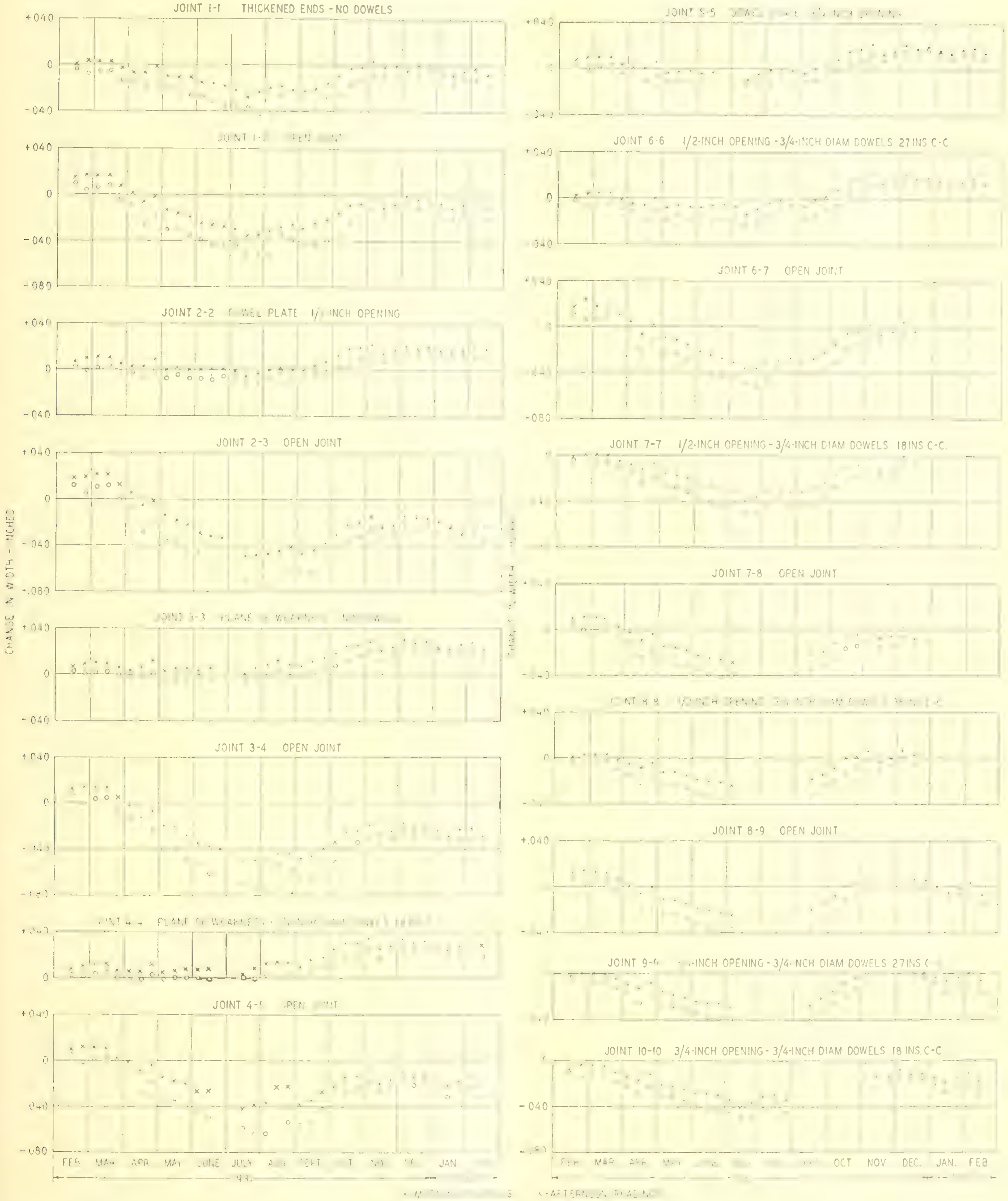

FIGURE 9.—SEASONAL VARIATIONS IN WIDTH OF EACH OF THE TRANSVERSE JOINTS OVER A TYPICAL 1-YEAR PERIOD. JOINT OPENING SHOWN AS POSITIVE, AND JOINT CLOSING SHOWN AS NEGATIVE. EACH VALUE IS A 10-DAY AVERAGE.

measurements of the variation in slab length with temperature changes that were presented in the second paper of this series. It will be remembered that these indicated that the deformation or change in slab length caused by the subgrade resistance during expansion or contraction is negligible in slabs of this length. It must be concluded, therefore, that the 10- by 20-foot slabs do not expand and contract symmetrically with respect to the subgrade at their midpoints. This eccentricity of movement is evident in all of the sections, although it is more noticeable in some than in others. It will be discussed in more detail a little farther on in this report.

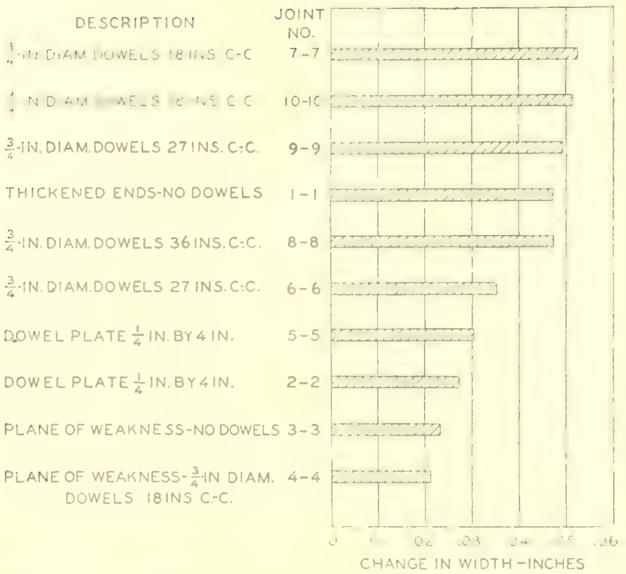

FIGURE 10.—MAXIMUM SEASONAL CHANGES IN WIDTH OF THE TRANSVERSE JOINTS. MAXIMUM RANGE FEBRUARY 16 TO JUNE 22, 1931. THE RANGES SHOWN ARE FROM THE AVERAGE MINIMUM AS SHOWN BY THE MORNING MEASUREMENTS ON COLD DAYS IN FEBRUARY TO THE AVERAGE MAXIMUM AS SHOWN BY THE AFTERNOON MEASUREMENTS ON HOT DAYS IN JUNE.

It will be observed further that several of the transverse joints opened more during the winter of 1932 than during the winter of 1931 and that consistently the adjacent open joints opened less during this same period and each by approximately the same amount. This condition is most noticeable in the two transverse planes of weakness (joint 3–3 and joint 4–4) and for the two joints containing the dowel plates (joints 2–2 and 5–5), and also, for some reason that is not apparent, in the dowelled joint 6–6. During 1931 these joints closed very little if any after March.

Figure 10 was constructed, from the same basic data that were presented in the preceding figure, for the purpose of showing the relative freedom of the different transverse joints to expand and contract. Selecting arbitrarily the period between February 16 and June 22 as giving a wide range in temperature, the average maximum range of movement for each of the transverse joints during this period was determined. In the preparation of figure 10, the daily values rather than 10-day averages such as are shown in figure 9 were used to obtain the average maximum and average minimum values. The indicated seasonal movements are therefore greater in figure 10 than in figure 9. The data for the joints are arranged in this figure in the order of descending values of the observed maximum seasonal movement. Since the sections are all of the same length and each is completely separated from its neighbors, the amount of movement which occurs at each test joint during a given period of time may be assumed to be a measure of the relative freedom of action so far as expansion and contraction are concerned.

Joint 1–1 was constructed as a clear opening one-half inch wide between two thickened-end slabs. It was filled with a bituminous joint filler shortly after construction. So far as the joint filler is concerned, it should offer relatively little resistance to expansion and contraction movements. The opinion has been expressed that this type of slab end exercises a restraining action that prevents the slab from contracting freely and causes a corresponding stress in the concrete, due to the inclined surface of the subgrade over which it presumably has to move.

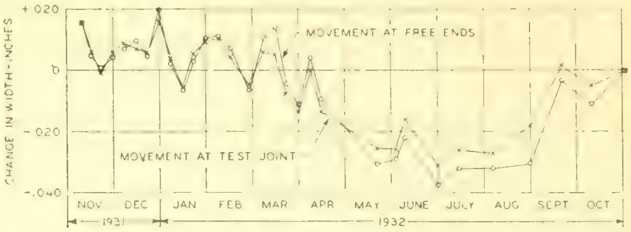

FIGURE 11.—COMPARATIVE MOVEMENTS AT THE TRANSVERSE JOINT AND AT THE FREE ENDS OF ONE OF THE TEST SECTIONS. POSITIVE VALUE INDICATES OPENING OF THE JOINT AND NEGATIVE VALUE INDICATES CLOSING OF THE JOINT.

In the second report of this series it was shown that, for the subgrade material and slab lengths concerned in these tests, the earth of the subgrade adhered to the bottom of the slab, "bending" or moving forward with the slab. Under such conditions the incline of the lower surface of the slab would not increase the resistance over that of a flat slab. It is indicated by the data in figure 10 that the thickened-end slab joint 1–1 permits the slabs to expand and contract as freely as any of the other transverse joints tested in this investigation.

Joints 7–7, 10–10, 9–9, 8–8, and 6–6 contain the unbonded, round, steel dowel bars. The movements at all of these are of approximately the same magnitude and about the same as that at joint 1–1, with the one exception of the seasonal movement of joint 6–6. There is no apparent reason why the seasonal movement of this one joint should be appreciably different from those of the other joints of the same type. The data indicate a high degree of relative freedom for the dowel joints with little or no variation in the restraint with the number of dowels per joint.

Other data, which supplement those shown in figure 9, were obtained in the measurements on section 10. These data are given in figure 11 in which the amount of movement at the test joint 10–10 and at the free ends of the section are shown at frequent intervals over a period of about 1 year. This section was separated from the one adjoining by an open space of considerable width. The expansion and contraction measurements were therefore made to fixed reference points at each end of the section. Since both ends were completely free the difference between the movements at the free ends when compared with the corresponding movements at the transverse test joint, as shown in figure 11, give a good idea of the degree of restraint developed in joint 10–10. In figure 10 this joint is among the group compared, hence a basis is furnished for estimating the order of restraint to expansion and contraction offered by each of the joints.

DOWEL-PLATE JOINTS OFFERED MORE RESISTANCE TO SLAB MOVEMENT THAN DID UNBONDED DOWEL BARS

For example, if the maximum movement found during the year shown in figure 11, i. e., November 1931 to November 1932, for joint 10–10 is expressed as a percentage of the movement measured at the completely free slab ends, it will be found that the movement at the joint was, in round numbers, 80 percent of that at the free ends of the test section. If this percentage is applied to the movement shown in figure 10 for joint 10–10, the analysis indicates that a movement for a completely unrestrained joint would be of the order of 0.065 inch. With this value as a basis, the restraining action of each of the 10 joint designs can be estimated.

It is indicated that joint 1–1, constructed as an open joint and filled with a poured joint filler, is not completely free and it seems likely that during the expansion of the concrete the compression of the filler material in the joint required an amount of force approximating that required to overcome both the resistance of the filler and the resistance of the dowels in each of joints 7–7, 10–10, 9–9, and 8–8. If this is so, then the force required to cause the dowels to slide in these joints must be very small, because the resistance of the joint filler to compression must be about the same in each of the joints in this group.

Joints 5–5 and 2–2 contained the one-fourth by 4-inch steel dowel plates. The measurements show that the seasonal movement of these two joints was approximately three-fifths of that of the dowelled-joint group (7–7, 10–10, 9–9, 8–8, and 6–6). It is indicated, therefore, that the plate-dowel joints offer a greater resistance to expansion and contraction than do joints containing properly installed round steel dowel bars which are not in bond with the concrete.

Joints 3–3 and 4–4 are the two transverse plane-of-weakness or dummy-type joints; the latter contain three-fourths-inch diameter dowel bars spaced 18 inches between centers. The seasonal movements of these joints are the smallest for any of the transverse joints. That this is caused by the complete closing of these joints in the early summer is clearly shown by the data already presented in figure 9. In examining this figure, attention is called particularly to the large movements of joint 3–4 lying between the two dummy joints. The closing of the dummy joints throws any subsequent expansion into slab displacement or slab deformation under stress. In such slabs the short slab length and the adjacent open joints provide the necessary relief from compression. The plane of weakness joints contract freely and relieve tension. Also, joints of this type undoubtedly reduce greatly the warping stresses. They do not appear to relieve slab expansion to any great extent, however.

Figure 12 shows data obtained during a cycle of measurements of width made at each of the transverse joints at approximately 2-hour intervals over a period of 24 hours. As noted in the figure, these particular observations were made during the latter part of June 1931, the time of year when large temperature differentials are developed in the test slabs.

On the same day that the daily variations in transverse joint width shown in figure 12 were obtained, the warped shapes of the slabs were measured at intervals of approximately 2 hours with the clinometer. From these clinometer data, curves similar in character to those shown in figures 25–28 and 31 of the second paper of this series were obtained. These curves were plotted to suitable scales and the slope of the upper surface at the extreme end of the pavement slab was estimated graphically. From this the change in slope of the vertical end face of the slab was determined for the rather extreme conditions of temperature warping which obtained on the particular day that the measurements were made. From this change in slope the effect upon the measurement of joint width was calculated and applied as a correction to the expansion

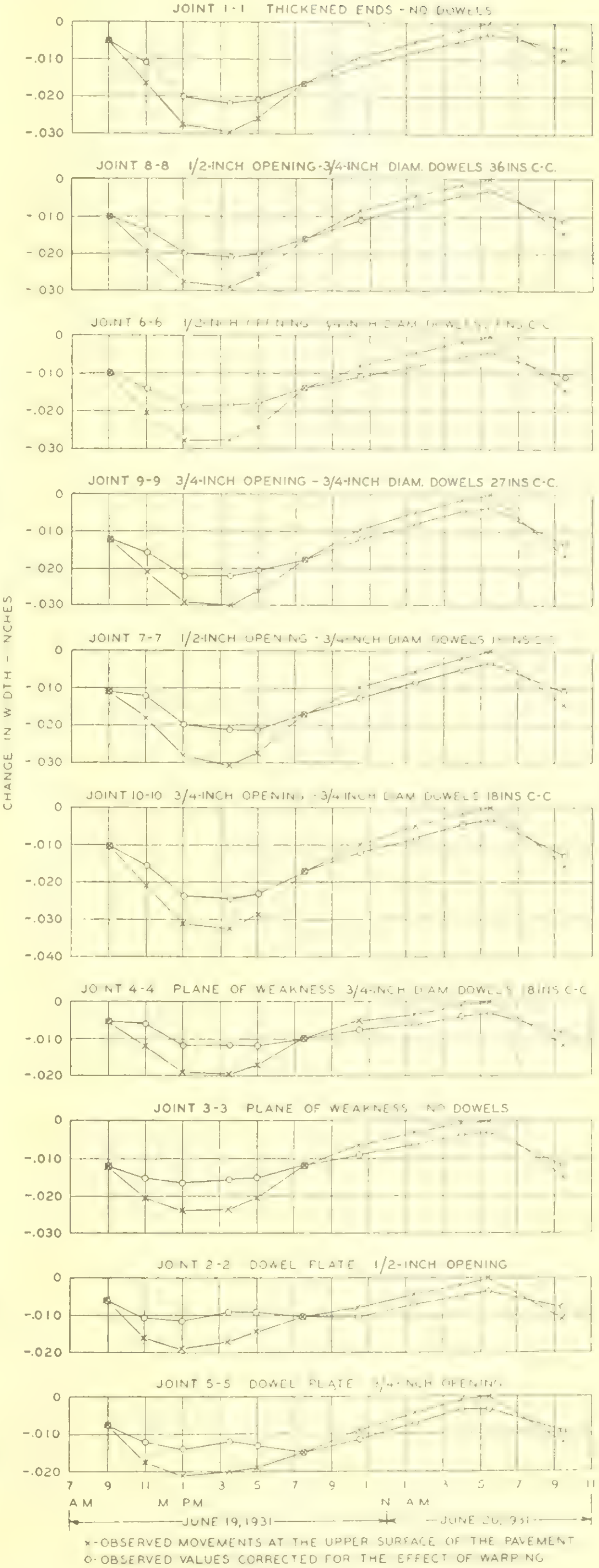

Figure 12.—Measured Changes in Width of the Various Transverse Joints Caused by Daily Changes in Temperature of the Pavement. Negative Values Indicate Closing of the Joint.

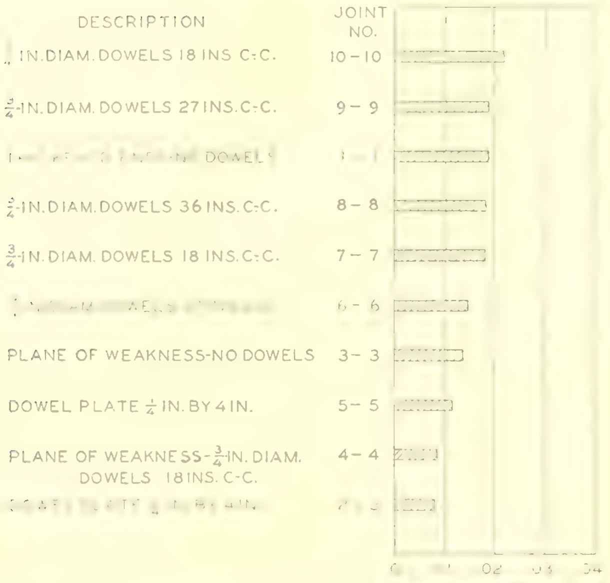

Figure 13.—Maximum Daily Changes in Width of the Transverse Joints.

and contraction measurements obtained at the transverse joints on the same day. Both the uncorrected and the corrected values are shown in figure 12.

It will be noted that the apparent change in joint width caused by the rather extreme temperature warping amounts to a closing of 0.007 to 0.009 inch during the day and an opening of 0.003 to 0.004 inch during the night. From the corrected curves of daily variations in joint width, figure 13 was constructed to show the relative extent of the true expansion and contraction that occurred at each transverse test joint for this particular June day.

In general the indications of figure 13 as to relative joint freedom are the same as those shown in figure 10 for the slower seasonal movements. The restraint to expansion and contraction offered by the dowel-plate joints is apparent in figure 13 and it appears that this restraint is greatest at the time when the slab edges are warped downward to the greatest degree. It is possible that slab warping causes an increase in the friction between the plate and its sockets and that the irregularity in these curves is caused by the variation in the frictional resistance as the extent of the slab warping varies.

ECCENTRICITY OF SLAB MOVEMENT DURING EXPANSION AND CONTRACTION STUDIED

In connection with the discussion of figure 9, mention was made of a tendency for the measured movement at the transverse test joints to differ in magnitude from that observed at the open joints at certain times and under certain conditions of temperature. A study of this relation has been made throughout the period of the investigation and much has been learned of its nature although the causes for the observed behavior are not entirely clear.

Figure 14 shows the movements at joint 3–3, a transverse plane of weakness without dowels. Figure 14 also shows the corresponding movements at the open joint 3–4 and maximum, minimum, and average air temperatures for a period of about two months during the winter of 1930–31.

It will be noted in this figure that frequently the movement at the test joint is of about the same magnitude as that at the free end, and yet whenever a marked temperature change occurs there is a tendency for the movement at the free end greatly to exceed that at the test joint. This effect is particularly noticeable during a sudden drop in temperature such as that which occurred between December 15 and 17, 1930. Whenever the observed movement at the free end exceeds that at the transverse joint, the slab is not expanding or contracting symmetrically with respect to the midpoint between the two, the slab panel being shifted as a whole toward the end at which the smallest change of position was observed.

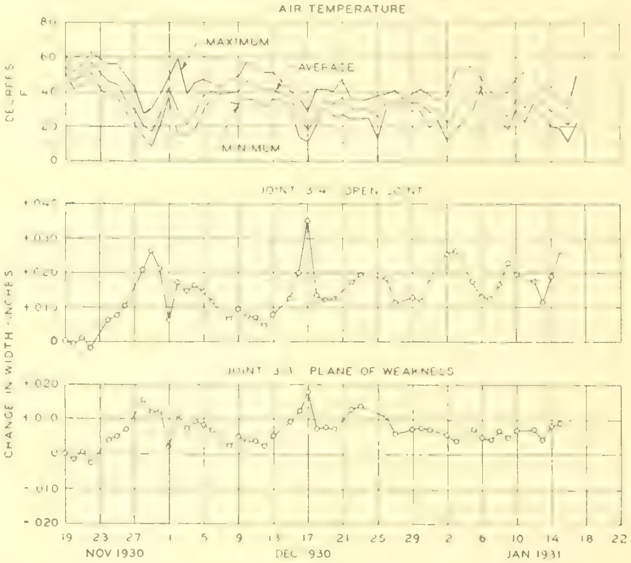

Figure 14.—Changes in the Width of Adjacent Transverse and Open Joints During a Period When Eccentric Movements Were Noted. Observations Were Made at 2 P. M. Positive Value Indicates Opening of the Joint and Negative Value Indicates Closing of the Joint.

This phenomenon was noticed on all of the test sections, being greater on some than on others, and being noticeably greater during the winter than in the summer. Also, it was greater during the first winter following the laying of the pavement than during the second winter, as can be seen by an examination of the data in figure 9.

To bring out the variation in the degree of eccentricity during the year, figure 15 was prepared from observations on section 7. The transverse joint in this section contained round dowels at 18-inch intervals. The movements of the transverse joint, expressed as percentages of that at the free end of the slab are shown as ordinates to the curve. It is interesting to note how this variation follows in a general way the annual variation in average daily air temperature, definitely indicating that the phenomenon is caused primarily by temperature. During the summer months the movements at the two points of measurement are nearly the same, but during cold weather the movement at the transverse joint is from 5 to 15 percent less than that at the open joint at the free end of the slab. As already stated, the difference was found to be greatest, for any particular season, at times of sudden change in temperature.

The observations were continued over a period of nearly 5 years in order to determine whether the movements tended either to open or to close the transverse joints or whether they were compensating in their effects.

The net change in width of each of the transverse joints and of each of the open joints on which measurements were made is shown, for the period between November 1930 and August 1935, in table 2.

TABLE 2.—*Changes in transverse joint width*[1] (*November 1930 to August 1935*)

Test joints		Open joints	
Joint no.	Net change in width	Joint no.	Net change in width
	Inches		*Inches*
1-1	+0.010	1-2	−0.074
2-2	+.096	2-3	−.089
3-3	+.093	3-4	−.108
4-4	+.110	4-5	−.090
5-5	+.072	5-6	
6-6	+.039	6-7	−.026
7-7	+.003	7-8	−.034
8-8	+.018	8-9	−.023
9-9	+.005	9-10	
10-10	−.024		

[1] The values shown are the net changes in joint width after the observed widths had been corrected for the estimated effects of pavement temperature difference and moisture difference, averaged for the two halves of the pavement (on either side of the longitudinal center joint) and expressed in inches per 20 feet of slab length. A positive sign indicates an opening and a negative sign a closing of the joint.

The data indicate that while all of the transverse joints, except that in section 10, opened to some degree, the two weakened-plane joints (3-3 and 4-4) and the two containing the dowel plates (2-2 and 5-5) apparently opened by about one-tenth inch during the period covered by the observations. In all of the other sections the opening has been very much less and in section 10 a slight closing has apparently occurred.

A comparison of the movement at the transverse joints with that at the open joints will show that the change in width has been accompanied by a corresponding change in the open joints. This indicates that some resistance to expansion and contraction existing at the transverse joint caused a permanent displacement of the pavement slab away from the transverse joint and toward the open joint. The magnitude of the displacement is probably a rough measure of the relative freedom of the various transverse joints to expand and contract.

In figure 20 of the second paper of this series data were presented to show the approximate magnitude of the force required to move a slab a given distance on this particular subgrade. An estimate of the restraining force developed by the different transverse joints may be made by finding the distance through which any particular joint causes the abutting slab to be displaced over the subgrade and then calculating the force required to cause this movement.

LONGITUDINAL JOINTS TENDED TO OPEN IN WARM WEATHER

The restraining forces were calculated in this manner for the four sections in figure 10 that show the least seasonal movement at the transverse joint (secs. 2, 5, 3, and 4), and the estimated unit stress developed by joint restraint in each is shown in table 3 with the data upon which the calculations were based. It is indicated that the dowel-plate joints caused restraint which may develop either tensile or compressive stresses of approximately 30 pounds per square inch, and the plane-of-weakness or dummy joint may cause compressive stresses of approximately the same magnitude. It is probable that if the slabs had been forced to expand and contract against the full resistance of their joints, instead of being comparatively free to shift their position as they were in these tests, a much more serious stress would have resulted.

FIGURE 15.—VARIATIONS IN THE ECCENTRICITY OF SLAB MOVEMENT COMPARED WITH THE VARIATIONS OF MEAN AIR TEMPERATURE. THE CURVES SHOW THE GENERAL TREND OF THE TEMPERATURE AND OF THE ECCENTRIC MOVEMENTS OF THE JOINTS BUT DO NOT INDICATE CHANGES THAT TAKE PLACE OVER SHORT PERIODS OF TIME.

The tendency for the joints to increase in width with time is of particular interest in connection with the weakened-plane joints when no dowels or other positive means for load transfer has been provided. The increase, though small, is a large percentage of the width of the original crack and it makes the load-transfer action of such joints problematical. It also creates a joint opening that is difficult to seal against moisture and solid matter.

TABLE 3.—*Estimated stresses resulting from joint restraint during expansion and contraction*[1]

Test section no.	Type of slab cross section	Type of transverse joint	Weight of slab, 10-foot width	Displacement of slab	Total computed thrusting force	Area of cross section	Estimated unit stress[2]
			Pounds	*Inches*	*Pounds*	*Sq. in.*	*Lbs. per sq. in.*
2	9-7-9	Dowel plate	18,250	0.025	25,550	875	±29
5	9-6-9	do	16,125	.022	21,350	774	±28
3	9-6.3-9 (A. A. S. H. O.).	Plane of weakness (no dowels).	17,775	.029	27,100	853	−32
4	9-6.3-9 (parabolic).	Plane of weakness (doweled).	18,000	.031	28,800	[illegible]	−[illegible]

[1] The period covered is the same as that shown in fig. 10.

[2] A positive sign indicates tensile stress and a negative sign indicates compressive stress.

The daily measurements of width of the longitudinal center joints of 6 of the 10 test sections over a period of about 1 year are shown in figure 16. Joints C-6 and C-7 are not shown, as they were constructed as planes of weakness and had not cracked through at the time of the measurements. Joints C-3 and C-10 had not been equipped with measuring points at the time of the measurements.

The measurements were made at the same time of day as those at the transverse joints, so that this graph shows the same relation as was brought out in figure 9, i. e., the maximum seasonal movements. In studying this graph it is well to bear in mind that the effective slab length in this direction is 10 feet and that all joints except C-4 and C-7 were crossed by bonded steel bars 4 feet in length. As noted above, joint C-7 had not cracked through at the time of the measurements but joint C-4 affords a good example of a free joint for purposes of comparison. It will be observed that the movement of this joint is approximately twice as great as that measured at the bonded joints.

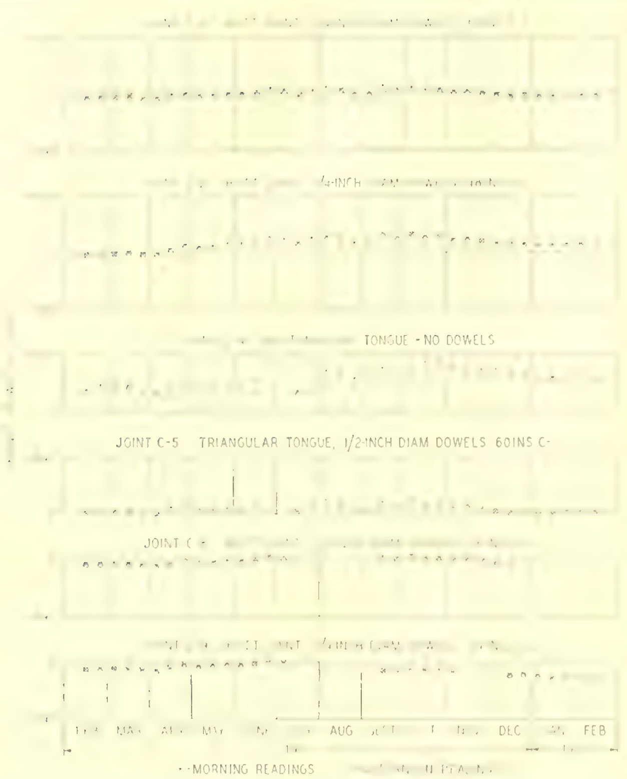

Figure 16.—Seasonal Variations in Width of Each of the Longitudinal Joints Over a Typical 1-Year Period. Joint Opening Shown as Positive and Joint Closing Shown as Negative. Each Value is a 10-Day Average.

These data indicated that in all cases the longitudinal joints tend to open as warm weather comes on, although a slight closing occurs each day as the slab expands with temperature. The possibility that this rather curious behavior was the result of temperature and moisture warping was investigated in the same manner as that described in the discussion of transverse joint movements. It was found that the change in slope of the slab edge at the longitudinal joint under extreme conditions of daily temperature warping might be as great as 10/10,000 for maximum downward warping (afternoon condition) and 2/10,000 for maximum upward warping (night condition).

The effect of moisture change was also investigated and it was found that from extreme upward warping from this cause (summer condition) to extreme downward warping (winter condition) a change in slope of the slab edge of about 12/10,000 occurred. The normal or unwarped condition of the slab, representing the condition where no moisture gradient was present, was not determined so that it is not possible to break down this total change in slope into its two components of upward and downward warping. The evidence indicates, however, that the slab is practically unwarped from this cause during the winter.

CERTAIN TYPES OF TRANSVERSE JOINT OFFERED LITTLE OR NO RESTRAINT TO SLAB WARPING

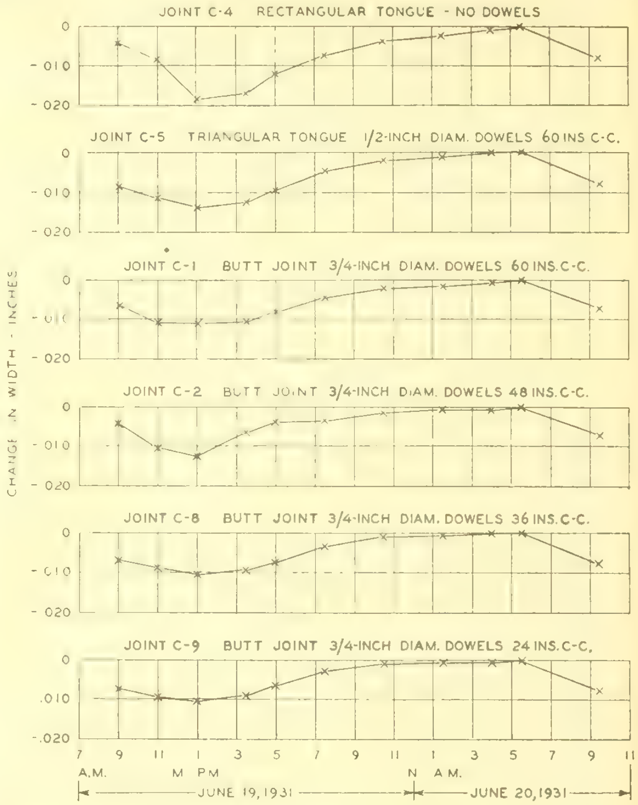

Figure 17.—Apparent Changes in Width of the Various Longitudical Joints Caused by Daily Changes in Temperature of the Pavement. A Negative Value Indicates Closing of the Joints.

Assuming that as warping occurs, joints containing dowel bars in bond either widen or close at the top of the slab and that at the plane of the bars the joint width remains constant, it is found that the total temperature warping would cause an apparent daily change in width of the longitudinal joint of a 7-inch slab (with the bonded dowel bars at mid-depth) of 0.008 inch. Since the total change in slope for extreme daily temperature warping equals that for total warping caused by annual moisture changes, it is probable that moisture change will produce an annual change in width of approximately the same magnitude.

The effect of the daily cycle of temperature changes is an apparent closing of the joint during the day and a corresponding opening during the night. The seasonal cycle of moisture variations should cause an apparent opening of the joints during the summer months and a closing during the winter.

This is in agreement with the observed behavior, as will be seen by referring to figures 16 and 17, which show the uncorrected measurements of longitudinal joint width during a 24-hour cycle of temperature changes. It is found that the magnitude of the observed variations agrees closely with what might be expected from the warping that was known to occur.

While the method of computing the effect of warping on joint width is necessarily an approximate one, it is believed that these computations show quite definitely that a large part of the apparent variation of longitudinal joint width shown in figures 16 and 17 is caused by slab warping and that, in the case of the joints containing bonded steel, there was in reality little or no opening and closing caused by expansion and contraction.

Joint C–4 is a rectangular tongue-and-groove joint without bonded steel. There is a tendency for this joint to increase in width with time. It is not known how long this progressive opening will continue but the fact that it has opened is of particular interest as indicating the probable movement of the longitudinal

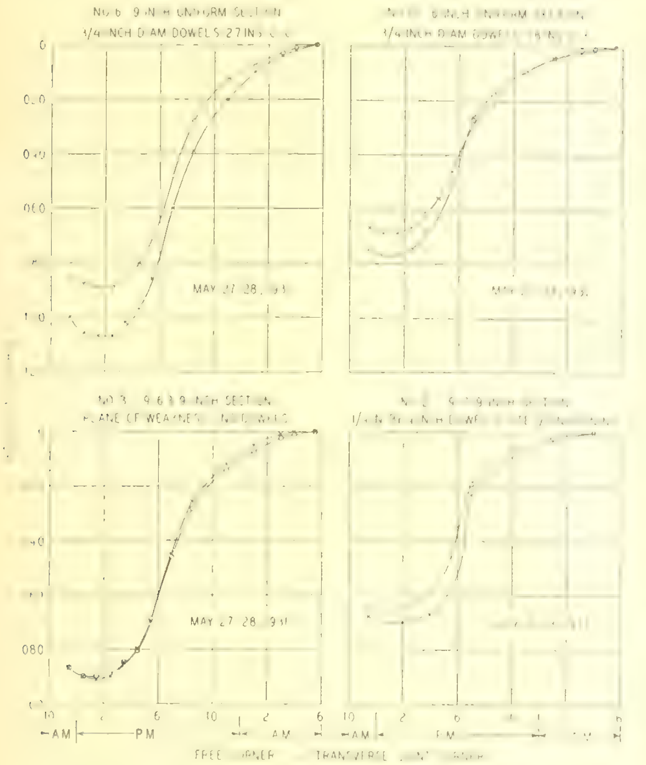

FIGURE 18.—COMPARISON OF THE CYCLES OF TEMPERATURE WARPING MOVEMENTS AT THE TRANSVERSE AND FREE JOINT CORNERS OF TYPICAL SLABS.

plane-of-weakness joint (C–7) had this joint been cracked through at the time.

A study was made of the relative vertical deflections at the free and the joint edges of the various slabs to determine the magnitude of the restraint offered by the various transverse and longitudinal joints. The deflected or warped shapes of the slab axes were measured with a clinometer and the cycles of vertical displacement of slab corners were measured with micrometer dials. Typical deflection data obtained from these measurements are shown in figures 18 to 21, inclusive. Since there were no thermocouple installations in the majority of the slabs, it was not possible to determine exactly the time at which the different slabs were of constant temperature throughout their depth and hence were in the unwarped condition. Therefore, for these particular comparisons, the total change that occurred during a full daily cycle is used in each case.

The extent of the vertical displacements caused by temperature warping at both the free and the transverse joint corners of several of the test sections are shown in figure 18. Since the deflection resulting from warping is greater at the corner than at any other point along the edge, it seems reasonable that any restraining effect of the joint would be most apparent in deflection data obtained at the corners. For this reason any indications of restraint in this figure probably represent approximately maximum conditions.

Data for two doweled joints, a dummy joint, and a dowel plate are included in this figure. Data for the doweled joint with the dowels at 27-inch intervals indicate some resistance to warping, while those for the other doweled joints in which dowels are installed at 18-inch intervals actually show a greater deflection at the joint corner than at the free corner. This is rather typical of much of the data obtained during these particular measurements. At times the free corner would show a slightly greater range of deflections than the joint corner and again, at some other time, the reverse would be true. The differences were generally so small as to be of no great importance in interpreting the data. The data for the transverse weakened-plane or dummy joint and for the dowel-plate joint indicate quite definitely that little or no restraint to warping is offered by either design.

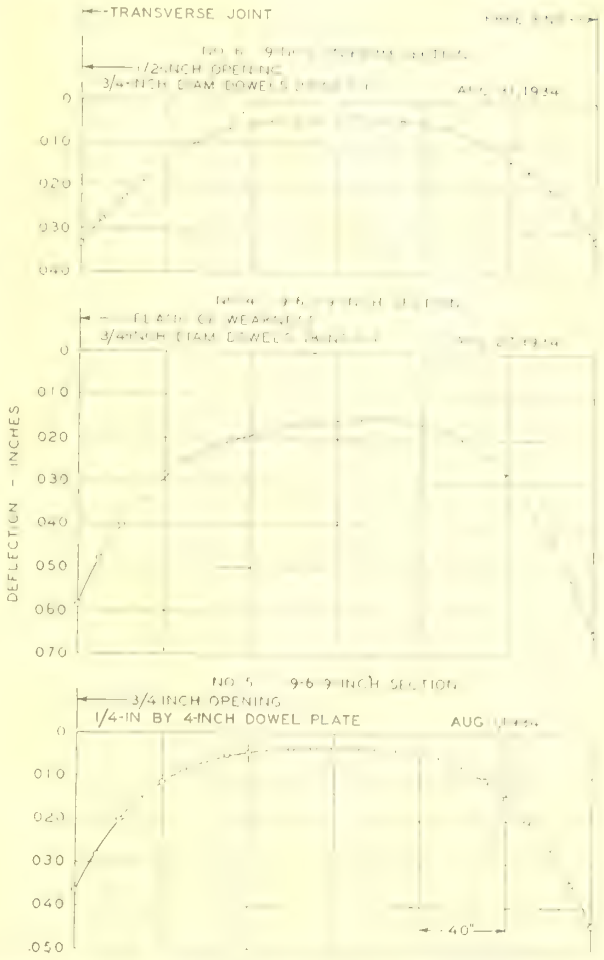

FIGURE 19.—TEMPERATURE WARPING DEFLECTIONS ALONG FREE EDGE OF TYPICAL SECTIONS.

In figure 19 the effects of temperature warping along the free edge of several of the sections are shown for days on which relatively large temperature variations occurred. The zero or base values for these curves were observations made at approximately 6 a. m. in each case, while the other set was made in the early afternoon at the time of maximum downward warping of the slab edges. An indication of the degree of restraint to warping offered by several transverse joints is obtained by comparing the warping at the transverse joint with that at the free end of the slab.

The joint types covered by figure 19 are the same as in the preceding figure, except that the dummy joint shown in figure 19 contains dowels and the dowel-plate joint has a different joint opening. The indications of this graph are in general agreement with those of figure 18 and, so far as these deflection data go, one would conclude that none of the designs of transverse joints included in these observations show any indi-

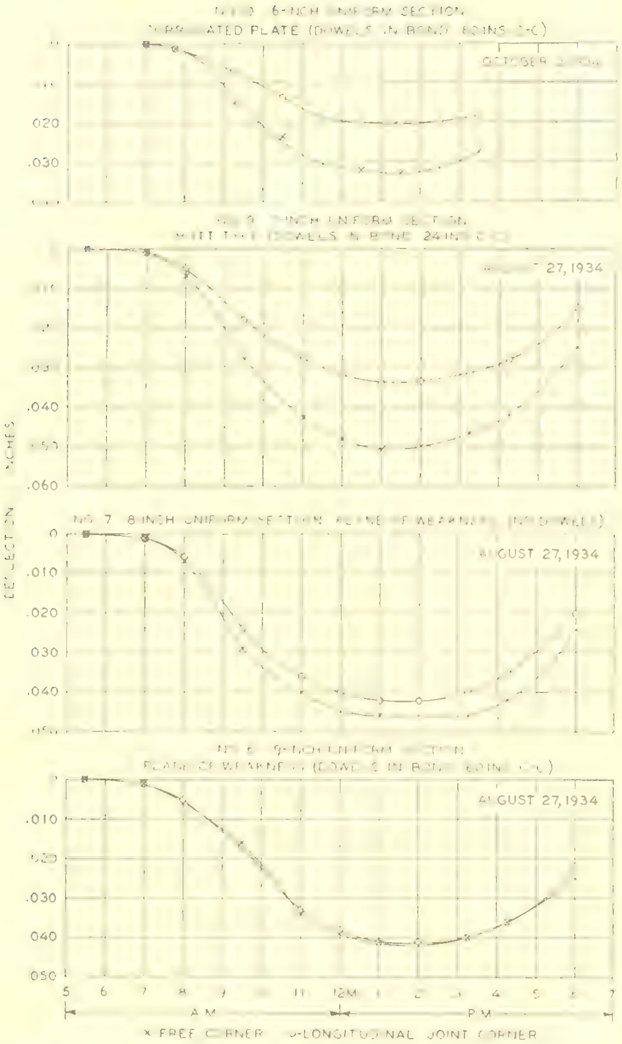

Figure 20.—Comparison of the Cycles of Temperature Warping Movements at the Longitudinal and Free Joint Corners of the Slabs of Uniform Thickness.

cation of offering serious resistance to warping. Final judgment as to the efficiency of the various joints in permitting warping should be reserved until certain stress data to be presented later are examined.

CERTAIN TYPES OF LONGITUDINAL JOINT OFFERED NOTICEABLE RESTRAINT TO SLAB WARPING

In the case of the longitudinal joints the study of the effect of the joint design on the restraint to warping, based upon the deflection data, was restricted to the four sections having a constant slab thickness; in all of the others the thickening of the free edges prevented a direct comparison of deflection data obtained at the joint with those obtained at the free edge of the slab. Fortunately, the more important types of longitudinal joint are represented in these four sections, as shown in the following summary:

Types of longitudinal joint:	*Slab thickness Inches*
Corrugated plate with bars at 60-inch intervals	6
Butt joint (tarred felt) with bars at 24-inch intervals	7
Plane of weakness. No bars	8
Plane of weakness with bars at 24-inch intervals	9

Figure 20 shows the relative magnitudes of the vertical displacements measured at the free and longitudinal joint corners of each of these four sections

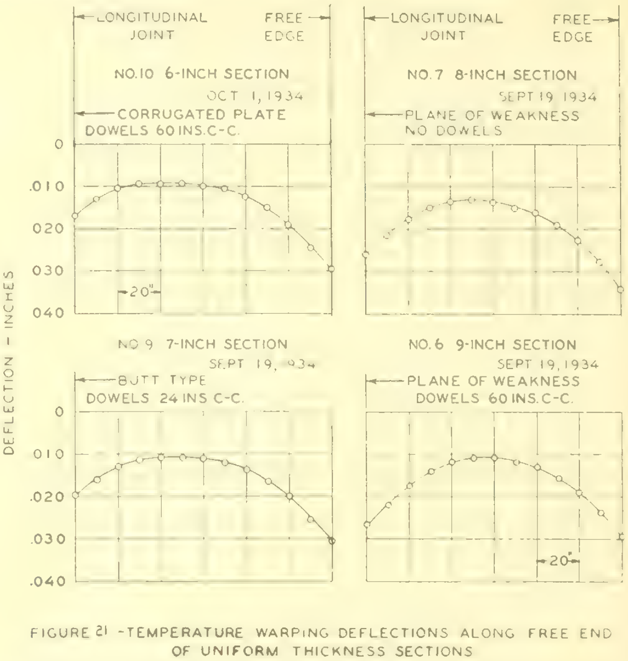

Figure 21.—Temperature Warping Deflections Along Free End of Uniform-Thickness Sections.

over a full daily cycle. The method of measurement was the same as that described in connection with the discussion of transverse joint action.

These curves indicate that the weakened-plane type of joint, which provides a greatly reduced section at the joint, caused very little restraint to temperature warping even when crossed by bonded steel. The butt-type joint and the type that contains a deformed, metal separating plate both appear to offer noticeable resistance to warping action.

Restraint to warping in joints that are crossed by bonded steel results from a resisting moment which develops between the tension of the bonded steel bars and the compression in the abutting surfaces of concrete in the two slab edges as the joint closes when the slab begins to warp. The length of the moment arm depends upon the distance to which the effective section extends either above or below the plane containing the steel. With the position of this plane fixed and at some point typical of general practice as, for example, halfway between the two surfaces of the slab, a relatively deep groove in the upper surface such as is present in weakened-plane joints greatly reduces the moment arm for the condition of downward warping and effects a corresponding reduction in the restraint. Restraint to upward warping would not be relieved by such a groove, however. Joints that contain little or no reduction in section provide a greater moment arm and, with other conditions the same, will develop more restraint to warping.

Curves showing the change in slope and the extent of the warping that occurred across the free end of each of the constant-thickness slabs during some particular day are shown in figure 21. The data were obtained with the clinometer in the manner previously described. The evidences of restraint shown by these data are in accord with what was shown by figure 20.

Additional information on the relative restraint to warping of the various transverse joints was obtained as a result of stress determinations based on strain measurements made at the positions shown in quadrant

4 of figure 8. The two gages placed perpendicular to and 6 inches from the free edge were used as index gages and the average deformation measured at these points, when corrected by means of Poisson's ratio for the strain measured by the gage parallel to the slab edge, was used as a base for computing the strains caused by restrained warping at other points.[15]

Stress values obtained in this manner for typical cases of warping for certain of the transverse joints are given in table 4 and for the longitudinal joints in table 5. A comparison between the stresses found at corresponding points near the joint edge and free edge of a slab panel, for a given temperature condition, brings out the effect of the joint on the stresses caused by warping. For example, the stresses at a point 18 inches from the joint edge should be compared with those found at the same distance from the free edge.

TABLE 4.—*Warping stresses caused by the various transverse joints*

Date tested (1934)	Test section no.	Type of joint	Spacing of dowels	Longitudinal stress [1] 6 inches from transverse joint	Longitudinal stress [1] 18 inches from transverse joint	Longitudinal stress [1] 18 inches from free end	Transverse stress [1] 6 inches from transverse joint	Transverse stress [1] 6 inches from free end
			Inches	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
July 19	7	Doweled	18	+5	+32	0	...	...
July 26	7	do	18	+20	+5	−50	...	...
June 28	4	Plane of weakness.	18	−68	−25	−35	−12	+59
June 29	4	do	18	−93	−35	−30	−14	+22
June 30	3	do	None	+69	+80	−10	−5	−65
July 3	3	do	do	+97	+100	+15	+42	+13
Sept. 20	2	Dowel plate	Continuous	−25	−22	+32	+56	+30
Sept. 28	2	do	do	−9	−42	+10	−14	−61
Sept. 10	4	Crack	None	−140	−140	−25	...	...

[1] A positive sign indicates tensile stress and a negative sign compressive stress in the upper surface of the slab.

TABLE 5.—*Warping stresses caused by the various longitudinal joints*

Date tested (1934)	Test section no.	Type of joint	Dowel spacing	Transverse stress [1] 6 inches from joint	Transverse stress [1] 18 inches from joint	Transverse stress [1] 18 inches from free edge
			Inches	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
July 7	[2] 3	Tongue	60	−53	−23	+40
July 11	3	do	60	−15	−10	+68
Aug. 22	[2] 5	do	60	−6	−57	−40
Oct. 3	10	do	60	−38	−60	−18
Sept. 18	9	Butt	24	+6	+28	+48
Sept. 19	9	do	24	−20	+8	+38
Sept. 26	[2] 2	do	48	−68	−80	−18
Oct. 2	2	do	48	−59	−90	−27
July 21	6	Plane of weakness	60	−41	−65	+2
July 24	6	do	60	−7	−42	+55
July 16	7	do	None	−20	−25	−15
July 17	7	do	None	−17	−32	+10

[1] A positive sign indicates tensile stress and a negative sign compressive stress in the upper surface of the slab.
[2] Thickened-edge slab.

DATA SHOW THAT JOINTS SHOULD OFFER A MINIMUM OF RESTRAINT TO WARPING

Since the deformations were all measured in the upper surface of the pavement for a condition in which the edges of the slab were warping downward, restraint to warping would be expected to cause an increase in the compressive stresses at the positions near the joint edge over those found at corresponding positions near the free edge.

A number of tests were made on thickened-edge slabs. The fact that a slab has thickened edges should not affect the stress comparisons so far as the transverse joints are concerned but the comparisons for the longitudinal joints are affected because the index gages, being at the thicker, outside edge of the slab, will record a larger deformation for a given degree of bending than will the gage at a corresponding position near the thinner, longitudinal joint edge. In the case of transverse stresses, the stresses themselves are small and the effect at the thickened edge does not appear to be important. In the case of the longitudinal stresses, however, the effect is more important and these data have been omitted from table 5 for this reason. It is indicated by both the deflection and stress data that none of the longitudinal joints causes any serious restraint to warping in the direction parallel to the joint.

It will be noted that the stress values given in tables 4 and 5 are generally small and that they tend to be erratic. It is believed that the tendency for the stress values to be erratic is caused in part by the variable behavior of the slabs, which was mentioned previously in connection with the deflection data, and in part by the small deformations and relatively few measurements involved. In most of the other stress determinations in these investigations it was possible to average a considerable number of observations of deformations which in themselves were of much greater magnitude than those being considered here. It may be said, however, that the stress data show no indications of serious restraint to warping in any of the designs tested.

Attention is called to the fact that the tests on the weakened-plane joints were made during the summer, when the joints were closed, a condition which should produce the maximum restraint to warping in slabs of the length used in these tests.

The crack in one of the slabs of section 4 was tested as a joint and, as shown by the data in table 4, appeared to exert a greater restraint to warping than any of the joint designs. There are probably two related causes for this. The first, and probably the most important, is the firm connection of the cracked panel with the adjoining uncracked panel by a tongue-and-groove type of longitudinal joint which exerted a stiffening effect on the cracked panel. The second is that the two broken edges of the cracked panel appeared to be tightly in contact at all times.

For warping to take place it is necessary to displace the two slabs abutting the crack longitudinally a slight amount. Except for some frictional resistance in the longitudinal tongue-and-groove joint the only force resisting this longitudinal movement is the resistance to deformation of the subgrade material, the magnitude of which varies with the length of the slab. In this particular case the resistance must have been quite small because the slab length was only 10 feet. In longer slabs, forces of considerable magnitude might easily be created at times when the concrete was in an expanded condition and the cracks tightly closed, although the presence of the crack tends to ameliorate the warping stress conditions in its vicinity.

The deflection and stress data just presented to show the relative degree of the restraint to warping offered by the various joints tested in this investigation are but a part of the data obtained although they are typical in all instances. To some extent they are erratic but it is believed that in spite of this the deflection and stress data both indicate that none of the joint designs which were tested are sufficiently resistant to bending to offer serious restraint to warping. The data do point to the danger of designing joints which are resistant to bending because of the warping stresses that such designs are likely to cause to be developed at times when warping of the slab occurs. It is indicated that a fundamental structural requirement in joint designs should be that the resistance to bending in both directions, but particularly in a plane perpendicular to the direction of the joint, be a minimum in order that the stresses caused by warping restraint will be as small as possible.

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[15] For a discussion of the formulas and methods of computing these stresses the reader is referred to the second report of this series published in PUBLIC ROADS, vol. 16, no. 9, November 1935.

STUDY MADE OF THE RELATIVE ABILITY OF VARIOUS JOINTS TO STRENGTHEN THE JOINT EDGE OF THE SLAB

The third group of tests of joints was planned to develop data that would show the relative effectiveness of the different designs from the standpoint of their ability to reduce the natural weakness of the slab at the joint edge. With the one exception of the thickened ends used at the transverse joint in section 1, this strengthening of the slab edge was accomplished through a transfer to the adjacent slab of a part of any load applied near the joint. The influence of the several designs on the deflections and on the stresses in the vicinity of the applied loads will be brought out in the discussion which follows.

Figures 22 to 25 contain data showing how the various parts of the different slabs deflect under the influence of loads applied at the points designated in the figures. The curves show the measured deflections for the two slabs abutting the joint under test, and, for comparison, the deflection of a corresponding edge or corner under the same load but lacking the support of a connecting joint. For example, in figure 22, which shows the deflections of the outside edge of the test section, a load applied on one side of the transverse joint deflected the two abutting slab ends in the manner shown by the crosses, while the same load placed near the free end of the outside edge produced the deflection of the free end which is indicated by the circles. Referring back to figure 8, which shows the location of the lines of clinometer points in the four quadrants, the crosses in figure 22 show deflections at points along the line A_3—A_2 for a load at C_3 while the circles show the deflections at points along the line E_3—A_3 for the same load at E_3.

In making an estimate of the ability of the various joints to reduce the deflection of the slab edge on which the load is applied, certain assumptions have been made:

1. If the joint design has a maximum of effectiveness in performing this function, a load placed on one side of but close to the joint edge should cause equal deflection of the two slab ends that abut the joint.
2. If the joint design is completely ineffective in this respect, a load on one side of, but close to, the joint should produce no deflection of the slab end on the opposite side of the joint.

The first and second assumptions serve as the basis for the first method of estimating joint effectiveness from the deflection data. The method will be described in a succeeding paragraph.

3. If the joint design has a maximum of effectiveness, the application of a given load at the joint should produce a deflection having a magnitude one-half as great as that which would be produced by the same load acting at an unsupported edge.
4. If the joint design is completely ineffective, a given load will cause the same deflection when applied at the joint edge and at a corresponding point of the free edge of the test slab.

The third and fourth assumptions are the basis of the second method of estimating joint effectiveness from the deflection data.

It is believed that all of the assumptions are correct for the condition of complete and uniform contact between the slab and the subgrade, because, for such a condition, the load-deflection relation is practically linear for loads within the safe stress range. It is indicated by these tests that this condition rarely prevails and that the extreme edges of the slab are in full contact with the subgrade only when they are warped downward.

Since the joint tests were made with the slabs in an unwarped condition brought about by the protective coverings described in the first report, the edges of the panels were not in full contact with the subgrade at the time the loads were applied, with the result that the load-deflection relation is not linear. A typical example of the character of this relation for a load applied at the free corner of one of the test sections is given in figure 26. It will be noted that for equal increments of load, each succeeding increment causes a somewhat smaller increment of deflection. This condition affects the third assumption because, for a given load, the free edges and corners are generally deflected more than the joint edges and corners. The third assumption therefore does not apply strictly to the conditions under which the tests were made and this fact should be considered in the application of these data.

On the basis of these four assumptions it is possible to estimate the extent to which the various joints are effective in reducing the deflection of the loaded joint edge, by making use of the deflection data given in figures 22 to 25, inclusive.

DEFLECTION OF LOADED SIDE OF JOINT ALWAYS EXCEEDED THAT OF ADJACENT SIDE

Two methods are available for making such an estimate. As noted previously, the first method makes use of the first and second assumptions, while the second method makes use of the third and fourth assumptions. Figure 27 shows the comparisons that are involved in each method of analysis.

While it is believed that the first method is probably the better measure of the ability of the joint design to reduce deflection because it does not involve the third assumption, both methods are of some value and will be used in the comparisons which follow.

Figure 22 shows the deflections along the outside edge of the various slabs caused by a load at points E_3 and C_3 and gives some indication of the effectiveness of the joint constructions in reducing the deflections caused by loads applied at the joint corners. For a load at point E_3 the shape of the deflected slab is shown between points E_3 and A_3, while for a load at point C_3 the shape is shown between points A_3 and A_2.

Figure 23 shows the extent of the deflections along the centerline of a 10- by 20-foot panel caused by loads applied either at point I_3 or G_3 and indicates the effect of the various transverse joints on the deflection caused by a load acting at a transverse joint at a point away from a longitudinal edge. For a load at point I_3 the shape of the deflected centerline is shown between

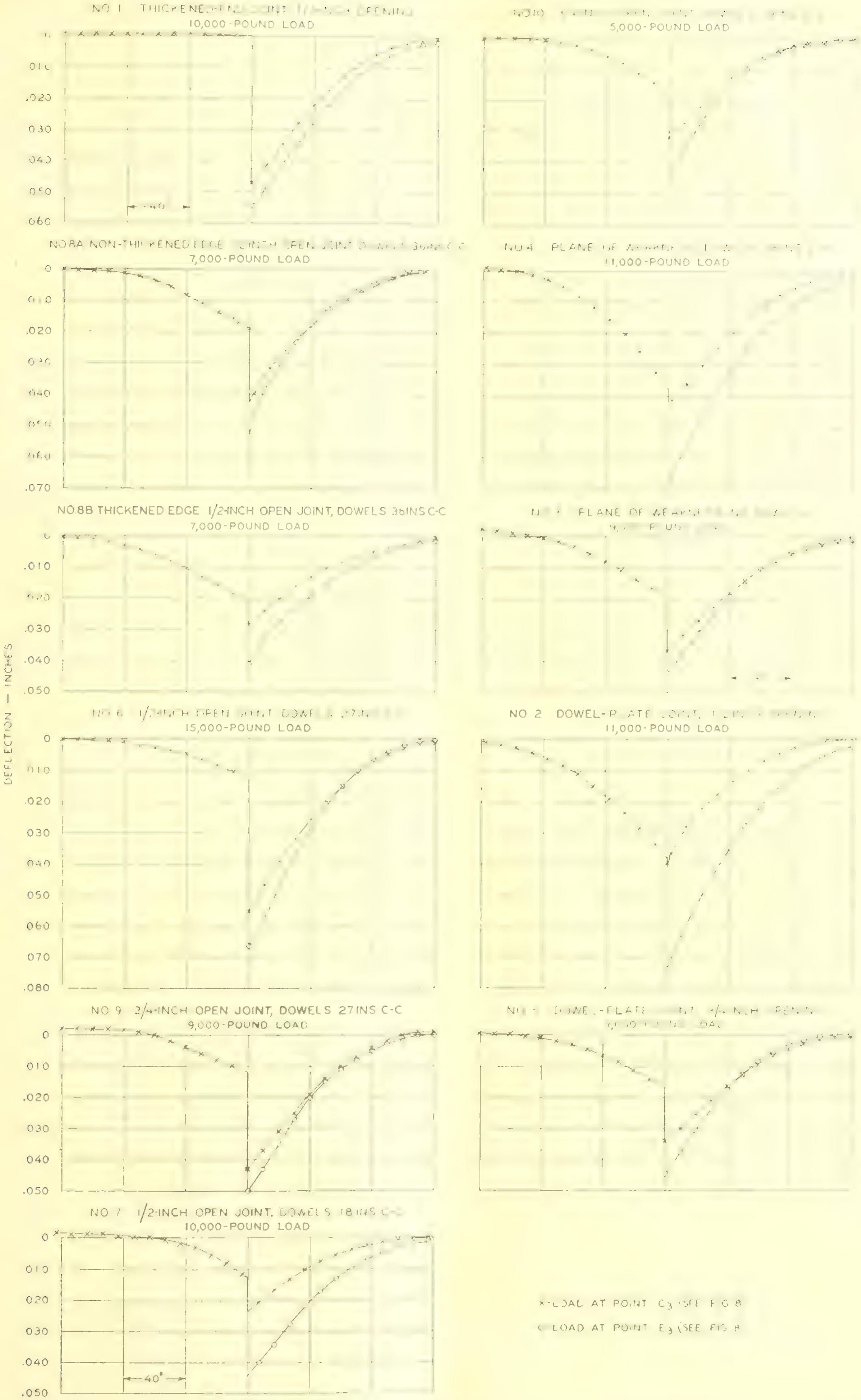


Figure 22.—Comparison of Deflections Along Free Edge of Test Panels for Loads Placed at Free Corner and at Corresponding Transverse Joint Corner. All Dowels Used in Transverse Joints Were ¾ Inch in Diameter and 36 Inches Long.

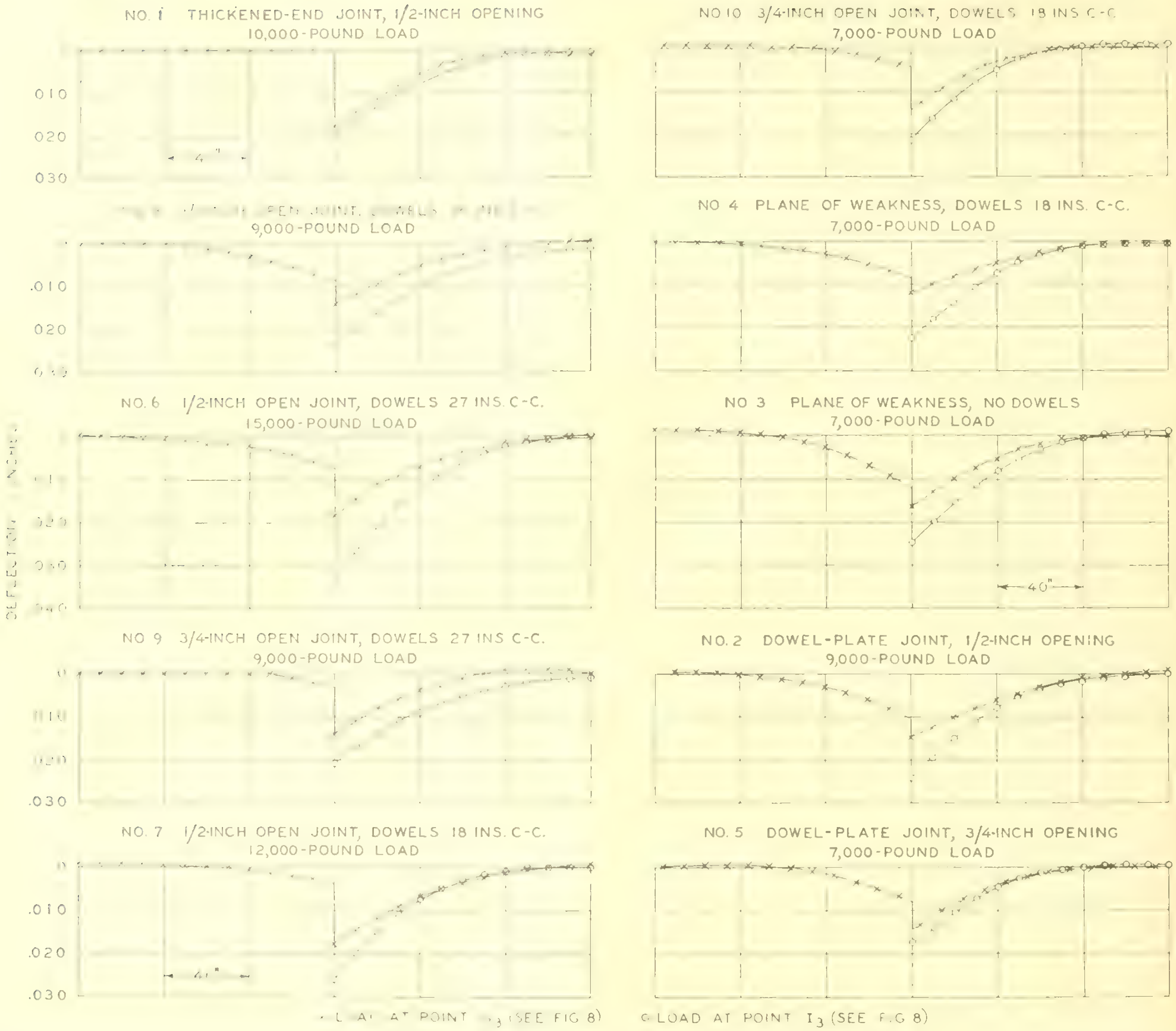


Figure 23.—Comparison of Deflections Along Longitudinal Centerline of Test Panels for Loads Placed at Midpoint of Free End and at Corresponding Point at Transverse Joint. All Dowels Used in Transverse Joints Were ¾ Inch in Diameter and 36 Inches Long.

points I_3 and H_3 while for a load at G_3 the deflections are shown between points H_3 and H_2.

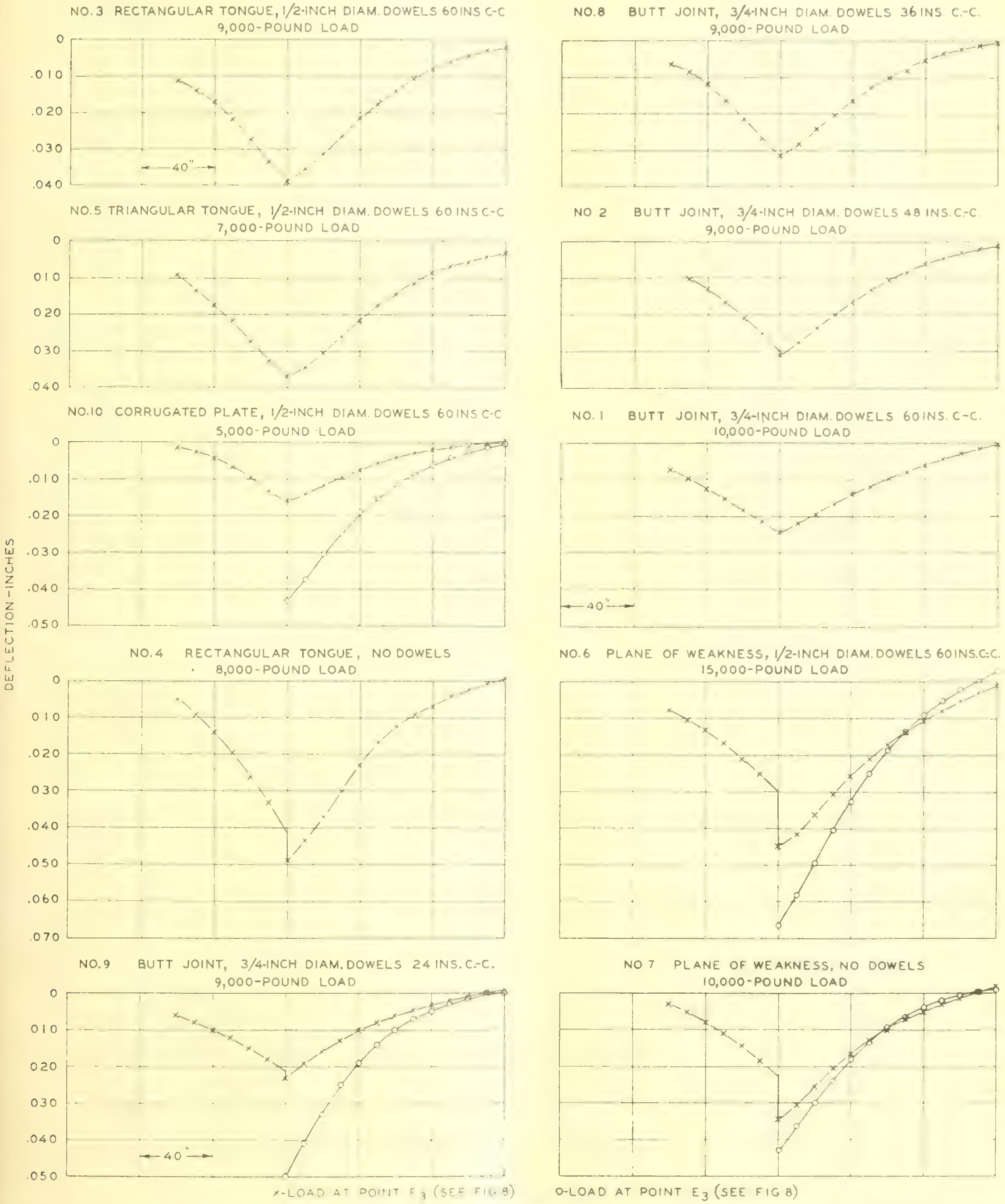
It will be observed that the data for transverse joint 1–1 (thickened slab ends) are included in these figures. Since there is a complete separation of slab ends in this construction and no load transfer is intended, these particular load-deflection data do not have the same significance as do those that apply to the other sections. As would be expected from the design, the two ends of the 10- by 20-foot panel behave in identical fashion and a load applied on one side of the transverse joint causes no deflection of the slab end on the other side of the joint.

Figure 24 shows the deflections along the end of the slabs caused by loads applied either at points E_3 or F_3 and indicates the effectiveness of the various longitudinal joints in reducing the deflections caused by loads applied at the joint corners of the slab. The shape of the slab is shown along the line E_3—F_3 for a load applied at E_3 and, similarly, with a load at F_3, the deflections between the points E_3 and I_4 are shown.

Figure 25 shows the deflections along the transverse centerline of a slab panel caused by loads applied at points A_3 and B_3, and these data indicate the ability of the various longitudinal joints to reduce deflection for loads applied near the longitudinal joint and at some distance from a transverse joint. For a load acting at point A_3 the deflections are shown between points A_3 and B_3, while for a load acting at B_3 the deflections are shown between points A_3 and H_4.

In the case of the thickened-edge slabs it is not possible to compare directly the deflections at the free and the longitudinal joint edges of the slabs. For this reason the comparisons in figures 24 and 25 are restricted to the constant-thickness sections.

In the data just presented for the transverse joints, it will be observed that the loaded side of the joint always deflects more than the adjacent side to which load is transmitted by the joint structure. The difference is greater for the joints containing the round dowel bars than for those which contain the dowel plates. There is also a variation in the magnitude of this differ-



NO. 3 RECTANGULAR TONGUE, 1/2-INCH DIAM. DOWELS 60 INS C-C
9,000-POUND LOAD

NO. 8 BUTT JOINT, 3/4-INCH DIAM. DOWELS 36 INS. C.-C.
9,000-POUND LOAD

NO. 5 TRIANGULAR TONGUE, 1/2-INCH DIAM. DOWELS 60 INS C-C
7,000-POUND LOAD

NO 2 BUTT JOINT, 3/4-INCH DIAM. DOWELS 48 INS. C.-C.
9,000-POUND LOAD

NO. 10 CORRUGATED PLATE, 1/2-INCH DIAM. DOWELS 60 INS C-C
5,000-POUND LOAD

NO. 1 BUTT JOINT, 3/4-INCH DIAM. DOWELS 60 INS. C.-C.
10,000-POUND LOAD

NO. 4 RECTANGULAR TONGUE, NO DOWELS
8,000-POUND LOAD

NO. 6 PLANE OF WEAKNESS, 1/2-INCH DIAM. DOWELS 60 INS. C.-C.
15,000-POUND LOAD

NO. 9 BUTT JOINT, 3/4-INCH DIAM. DOWELS 24 INS. C.-C.
9,000-POUND LOAD

NO 7 PLANE OF WEAKNESS, NO DOWELS
10,000-POUND LOAD

DEFLECTION-INCHES
0
.010
.020
.030
.040
.050
.060
.070
40"
×-LOAD AT POINT E3 (SEE FIG 8)
O-LOAD AT POINT E3 (SEE FIG 8)

FIGURE 24.—COMPARISON OF DEFLECTIONS ALONG FREE END OF TEST PANELS FOR LOADS PLACED AT FREE CORNER AND AT CORRESPONDING LONGITUDINAL JOINT CORNER. DOWELS ¾ INCH IN DIAMETER USED IN JOINTS C–1, C–2, C–8, AND C–9; DOWELS ½ INCH IN DIAMETER USED IN JOINTS C–3, C–5, C–6, AND C–10. ALL DOWELS IN BOND.

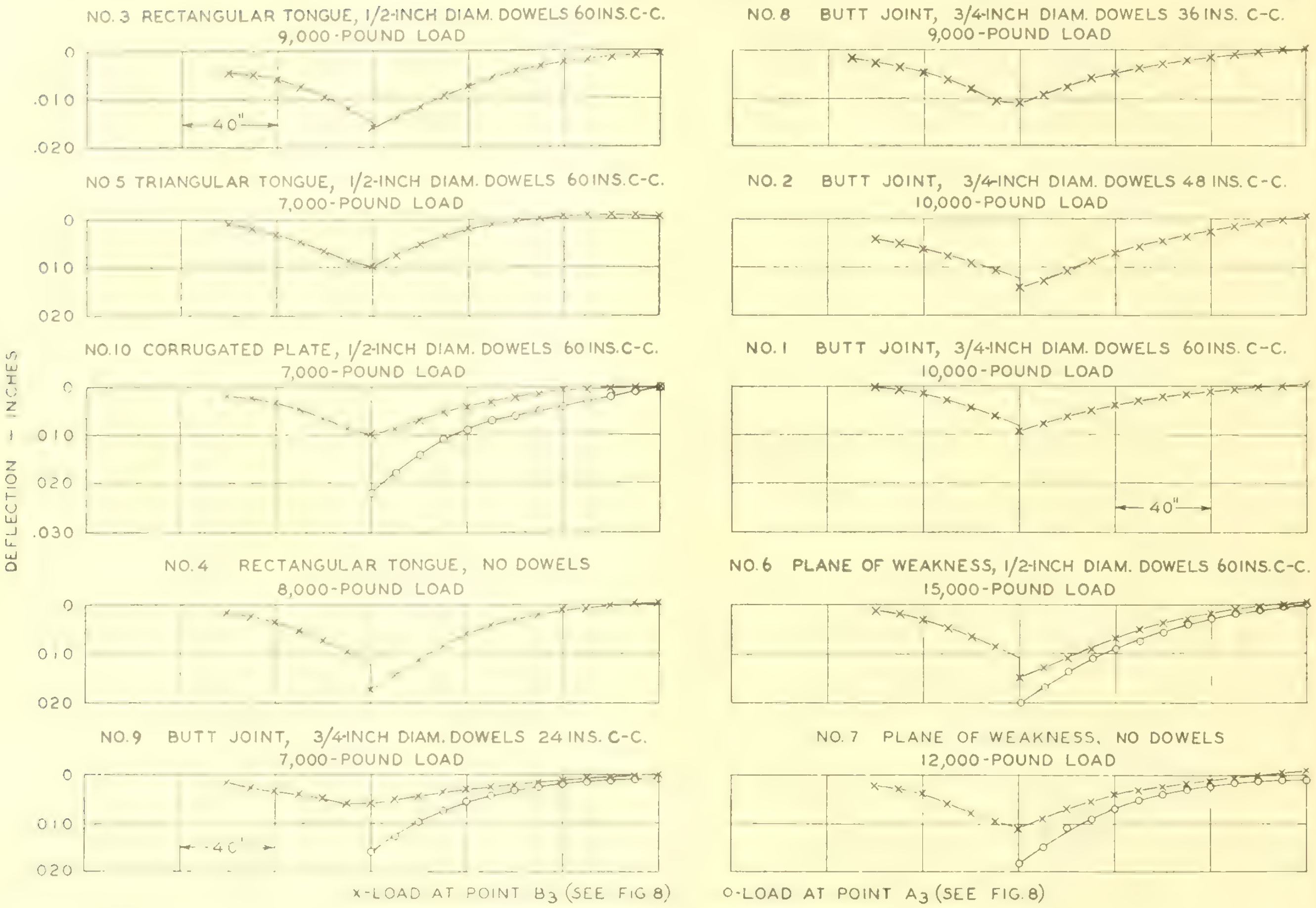


Figure 25.—Comparison of Deflections Along Transverse Centerline of Test Panels for Loads Placed at Midpoint of Free Edge and at the Corresponding Point at Longitudinal Joint. Dowels ¾ Inch in Diameter Used in Joints C–1, C–2, C–8, and C–9. Dowels ½ Inch in Diameter Used in Joints C–3, C–5, C–6, and C–10. All Dowels in Bond.

ence among the joints that contain the dowel bars. This variation might possibly result from a lack of stiffness in the dowel bars or from a looseness of the dowels in the concrete, or from a combination of the two. In order to develop information regarding the relative importance of each of these factors, a series of loads was applied on each of the four quadrants of two of the sections at a joint corner (point C) and at several points directly over dowel bars at some distance from the corners (near point G).

For the purpose of these comparisons it is assumed that, for a load applied on one side of a doweled joint, so long as the dowels are firmly in bearing on each side of the joint, the deflection rate of the adjacent slab end will bear a constant relation to the deflection rate of the loaded slab end. The ratio of the one to the other will be a constant as each load increment is applied. When the loaded edge begins to deflect, the adjacent edge will not follow immediately if any deficiency in dowel seating is present, and this lag will be evident as a variation in the ratio between the load deflection rates for those increments of load applied while the seating deficiency exists.

DATA ON LOAD-DEFLECTION MEASUREMENTS AT JOINT EDGES PRESENTED

Figure 28–A shows the load-deflection relation for both the loaded and unloaded joint ends at the corner of the panel, for sections 6 and 7, for a series of uniform increments of applied load. From the corresponding deflection increments "k" and "p", the mean slope ratio, $\frac{p}{k}$, was calculated for each increment of load and these values are plotted as ordinates to the curves shown in figure 28–B.

This graph indicates that the dowels at the corner of section 6 were slightly loose, because the ratio is smaller for the first load increments than for the later ones. Apparently the 6,000-pound load was sufficient to take up the dowel looseness completely, and it is noted that this load caused a maximum deflection of the loaded corner of about 0.016 inch. In the case of section 7 there is no indication of dowel looseness, the value of the ratio being practically constant for all load increments.

The flexibility of the dowels is indicated by the fact that for the upper increments of load the deflection of the adjacent slab corner is but 50 or 60 percent of that of the corner on which the load was applied.

The deflections of the loaded corners of the two sections are approximately the same for a given load despite the difference in slab thickness. The amount of support received from the adjacent slab corner is not the same in the two cases, however, and this probably accounts to a large extent for the effect noted.

Figure 29 contains data obtained in similar tests on section 7 in which the loads were applied directly over the dowels but at some distance from the longitudinal edges of the slab (near point G). These are average curves from tests made at several points on the same

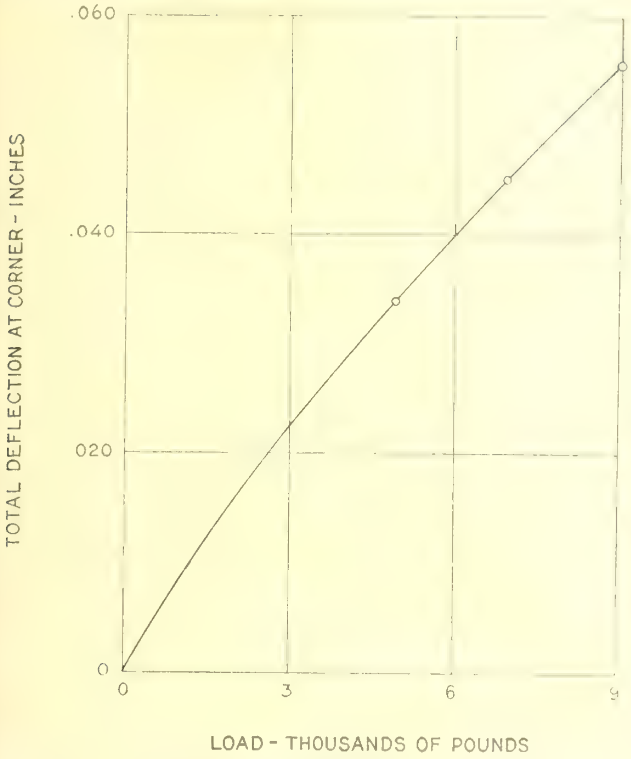
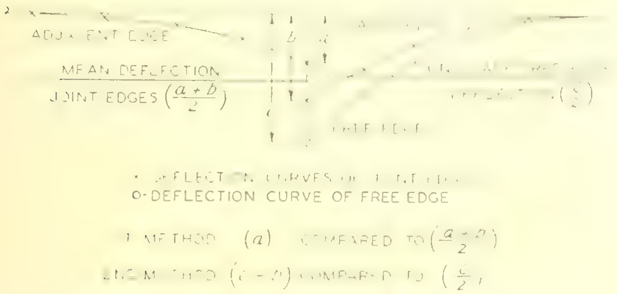


Figure 26.—Typical Load-Deflection Relation for a Load Acting at a Free Corner.



ADJACENT EDGE
MEAN DEFLECTION
JOINT EDGES $\left(\frac{a+b}{2}\right)$
O-DEFLECTION CURVE OF FREE EDGE

Figure 27.—Methods of Estimating the Effectiveness of Joints for Reducing Slab Deflection on the Basis of Load-Deflection Data.

slab and are plotted in the same manner as the data shown in the preceding figure. In this case it appears that the differences between the deflections of the two slab ends should be attributed entirely to dowel flexure, there being no indication of dowel looseness.

A comparison of the values of the slope ratios shown in the last two figures shows that the value is smaller for loads applied near the joint at points remote from the corner than for loads applied near the slab corner. This indicates that to obtain the same percentage of deflection across a doweled joint at all points a stiffer transfer medium is required at points that are away from the slab corner than is required in the immediate vicinity of the corner. Also a stiffer medium is required for thick slabs than for thin slabs.

It is thought that the data shown in the last two figures furnish an explanation for most of the differences found in the deflection data presented in figures 22 to 25, inclusive. In general, it was found that only a very few of the dowels were sufficiently loose to produce any apparent detrimental effect on the ability of the joint to transfer load. This is rather surprising when consideration is given to the very small deflections involved in this action. During construction considerable care was taken to place the concrete around the dowels properly, but typical field methods were employed in all of the operations and the condition of these dowels is considered representative of what can be obtained where dowels are carefully installed in first-class construction.

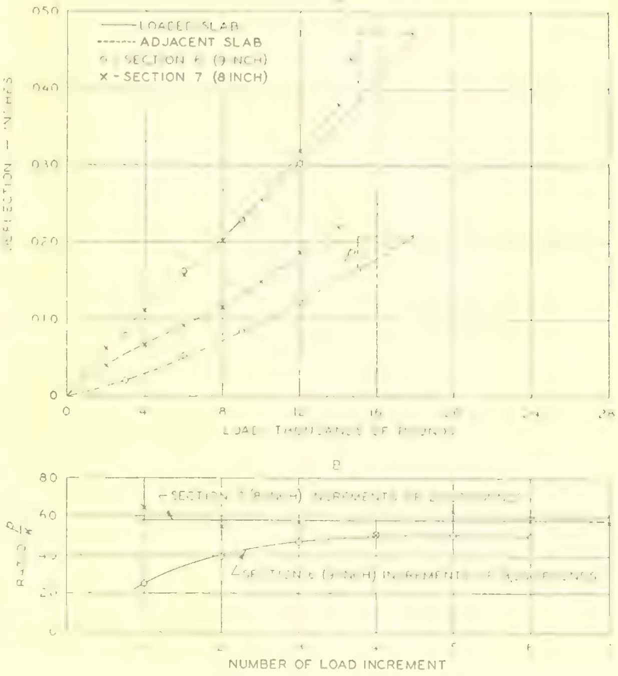


Figure 28.—Data on Study of Dowel Stiffness and Dowel Looseness, Transverse Joint Corners.

Figure 29.—Data on Study of Dowel Stiffness and Dowel Looseness, Transverse Joint Edges (Section 7).

Somewhat similar studies of the deflections of concrete pavement slabs caused by loads acting near joints have been reported by the State highway organizations of Georgia [16] and Michigan.[17] The data given in these two reports are in general agreement with those which have been presented in figures 22 to 25, inclusive.

TWO METHODS USED TO MEASURE EFFECTIVENESS OF JOINTS IN REDUCING DEFLECTION OF THE LOADED JOINT EDGE

Tables 6 and 7 were developed from the data shown in figures 22 to 25, inclusive, for the purpose of bringing out more directly the comparisons that appear to be significant. Table 6 applies to the transverse joints and table 7 to the longitudinal joints.

In columns 5 and 8 of these tables a comparison is made between the sum of the maximum deflections of the two slab edges abutting the joint in question and the deflection of a corresponding point at a free edge of the same slab, the load being the same in both cases. Referring to figure 27, the comparison of deflections involved in the computation of the values shown in columns 5 and 8 is expressed as a percentage of the free edge deflection by the formula

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[16] Tests of Load Transmission across Joints in Concrete Pavements, by Searcy B. Slack, Engineering News-Record, vol. 107, no. 2, July 9, 1931, p. 53.

[17] Tests of Aggregate Interlock at Joints and Cracks, by A. C. Benkelman, Engineering News-Record, vol. 111, no. 8, Aug. 24, 1933, pp. 227-232.

$$\frac{(a+b)-c}{c}$$

Columns 6 and 9 show the effectiveness of the various joints in reducing the deflection of the loaded edge by means of a comparison of the deflection of the unloaded joint edge with the mean deflection at the joint. This is the first method previously mentioned and the values are computed by the formula

$$\frac{a}{\frac{(a+b)}{2}}$$

Columns 7 and 10 give similar comparative values developed by the second method, the reduction in deflection effected by the joint being compared to one-half of the deflection of the free edge (a reduction of one-half of the free edge deflection would mean perfect joint action). This relation is expressed by the formula

$$\frac{c-b}{\left(\frac{c}{2}\right)}$$

Table 6.—*Various relations between the deflections caused by loads placed at the free and the transverse joint edges of slabs*

Test section no.	Type of joint	Spacing of dowels	Joint opening	Tests at slab corners: Sum of deflections at joint corner exceeds that at free corner by [1]	Tests at slab corners: Joint effectiveness estimated by first method	Tests at slab corners: Joint effectiveness estimated by second method	Tests at midpoint of slab end: Sum of deflections at midpoint of joint end exceeds that at midpoint of free end by [1]	Tests at midpoint of slab end: Joint effectiveness estimated by first method	Tests at midpoint of slab end: Joint effectiveness estimated by second method
1	2	3	4	5	6	7	8	9	10
		Inches	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
8	Doweled	36	1/2	18	73	50	−5	76	83
6	do	27	1/2	3	37	33	−22	57	88
9	do	27	3/4	10	44	28	−19	35	67
7	do	18	1/2	−18	70	94	−19	33	65
10	do	18	3/4	14	71	53	−14	47	67
4	Plane of weakness	18		19	95	74	−10	81	96
3	do	None		28	70	32	14	84	68
2	Dowel plate		1/2	5	97	92	4	82	77
5	do		3/4	13	66	48	27	70	31

[1] A negative sign indicates that the sum of the deflections of the two edges abutting the joint under test is smaller than the deflection of the corresponding point at the free edge of the slab.

The values in table 6 indicate that for a given load the sum of the deflections at the corner of a transverse joint is nearly always greater than the deflection of the corresponding free joint corner. At the transverse joint edge at a distance from the corner, in some cases the sum of the deflections at the joint edge exceeds the corresponding deflections at the free edge and in other cases it does not.

Table 7.—*Various relations between the deflections caused by loads placed at the free and longitudinal joint edges of the slabs*

Test section no.	Type of joint	Type of tongue	Spacing of dowels [1]	Tests at slab corners: Sum of deflections at joint corner exceeds that at free corner by [2]	Tests at slab corners: Joint effectiveness estimated by first method	Tests at slab corners: Joint effectiveness estimated by second method	Tests at midpoint of slab end: Sum of deflections at midpoint of joint end exceeds that at midpoint of free end by [2]	Tests at midpoint of slab end: Joint effectiveness estimated by first method	Tests at midpoint of slab end: Joint effectiveness estimated by second method
1	2	3	4	5	6	7	8	9	10
			Inches	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
3	Tongue	Rectangle	60		100			97	
5	do	Triangle	60		100			100	
10	do	Corrugated	60	−26	100	126	−12	100	111
4	do	Rectangle	None		91			83	
9	Butt		24	−12	96	108	−24	100	124
8	do		36		100			100	
2	do		48		98			92	
1	do		60		100			94	
6	Plane of weakness.		60	12	80	65	28	85	52
7	do		None	33	79	40	21	100	80

[1] All dowels across longitudinal joint were fully bonded.

[2] A negative sign indicates that the sum of the deflections of the two edges abutting the joint under test is smaller than the deflection of the corresponding point at the free edge of the slab.

Earlier in the discussion it was shown that the load-deflection relation at a slab corner is not linear because the slab is not completely in contact with the subgrade when the deflection begins and the conditions of support change gradually as the deflection progresses. It was shown in figure 26 that for equal increments of load the resulting increments of deflection gradually decrease as the magnitude of the deflection increases. It is thought that this is the reason that the combined deflections at a transverse joint corner nearly always exceed the corresponding deflection at a free corner. The free corner, on account of its relatively greater deflection, is able to offer more resistance to deflection. The values given in columns 5 and 8 of these tables are significant because they illustrate the point just discussed and help to explain differences in the values of joint effectiveness as estimated by the two methods of analysis.

When the loads are applied at the slab edges at some distance from a corner, the deflections are all small, relatively. The effect of varying subgrade support is therefore much less.

It is apparent from table 6 that the two methods of analyzing the deflection data to determine the relative effectiveness of the transverse joint designs in reducing the deflection of the loaded edge of a joint give different values for the same joint design. For the corner loading the first method of calculation, with one exception, yields higher values, while for the interior edge condition the relation between the values obtained by the two methods of comparison is quite irregular. The most probable cause for this irregularity has already been mentioned. The values obtained by the first method probably give the better idea of the ability of the joints to transfer load, while those obtained by the second probably give a better indication of the relative ability of the joints to reduce the maximum deflection of the loaded edge. Neither method gives a complete measure of the structural efficiency of the joint to which it is applied, however.

WEAKENED-PLANE JOINTS CONTAINING DOWELS WERE EFFECTIVE IN REDUCING SLAB DEFLECTION

From table 6 it appears that the transverse joints that depend upon round dowels for their connection are not as effective in reducing maximum deflections as might reasonably be expected. The data for the joints having dowels spaced 18 and 27 inches apart, respectively, indicate that the effectiveness of the joint in reducing corner deflection is increased as the dowel spacing is decreased. The joint containing the dowel bars with a 36-inch spacing is not in line with the others in respect to this relation. Why this should be is not known, although the fact that this particular transverse joint was installed in the section having the lip-curb cross section may have been at least partly responsible. The two halves of this section (longitudinally) were different, so that there was opportunity for but one-half as many comparisons as on the other sections. Also, because of the presence of the lip curb on the upper surface, certain difficulties in duplicating loading conditions were always present in the tests on this section.

So far as the values computed from the deflection data indicate, dowel spacing within the limits of the tests did not influence the effectiveness of the doweled joints in reducing the deflection of the loaded edge. Neither do they show any consistent difference attributable to the differences in the width of the joint opening used in these tests.

The tests on the transverse plane-of-weakness or dummy joints were made in November when the slabs were contracted and the joints were opened slightly. The comparative values for the weakened-plane joints containing dowels (particularly those computed by the first method) indicate a very effective construction so far as ability to reduce slab deflection is concerned. The joint without the dowels is also indicated as being quite effective by these values. It should be remembered in this connection that the slab length in which the joints were used is but 20 feet.

It is indicated further by the values in table 6 that the two joints containing the one-fourth by 4-inch dowel plates are effective in reducing slab deflection. When used with a joint opening of one-half inch the effectiveness of a dowel plate of this thickness seems to be noticeably greater than when used with a three-fourths-inch joint opening.

Table 7 contains similar comparative values for the longitudinal joints computed by both methods wherever possible. One is struck immediately by the generally higher order of values in this table when compared to those given in the preceding table for the transverse joints. This is a direct reflection of the better structural connection obtained in the longitudinal joints where little or no change in joint width occurs and no provision for slab expansion was necessary.

It will be noted in table 7 that the values computed for the corners of the longitudinal joints in sections 9 and 10 show that the combined deflections at the joint are less than the deflection at the corresponding free corners. This relation is the reverse of that generally shown in table 6 for the transverse joints.

As stated earlier, it was possible to make comparisons between the deflections of free and longitudinal joint edges of slabs only for sections of constant thickness and even then only two of the four constant-thickness sections (sections 9 and 10) were suitable for the desired comparison. The other two constant-thickness sections were of the plane-of-weakness type and only one of these contained bonded steel across the joint. It is believed, however, that the relations indicated for sections 9 and 10 will probably be found in any constant-thickness section in which the dummy-joint construction is not used and the slab edges are held in contact by bonded steel members across the joint. That such a design permits the development of a resisting moment during deflection has already been pointed out. The effect of this moment is to stiffen the joint against deflection under load and this would produce the relation indicated by the values in table 7. The magnitude of the moment that it is possible to develop will depend upon the effective depth of the slab at the joint, the amount and position of the steel capable of taking tension, any opening of the joint, and other factors.

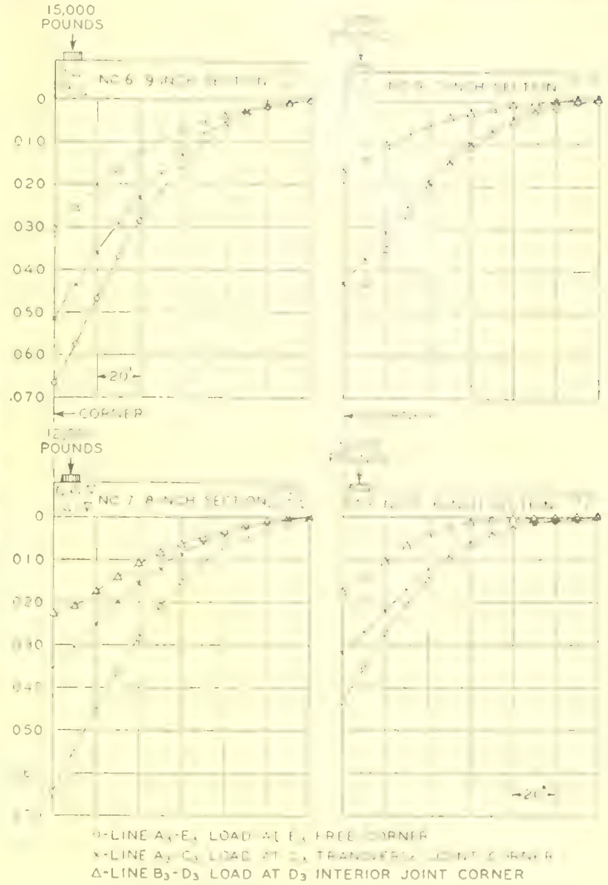

FIGURE 30.—COMPARISON OF DEFLECTIONS OF SLAB EDGES AT THE FREE TRANSVERSE JOINT AND INTERIOR JOINT CORNERS FOR THE UNIFORM-THICKNESS SECTIONS.

Table 7 shows that the sum of the deflections at the longitudinal joint exceeds that at a corresponding point at the free edge in the two plane-of-weakness joints. For the other two sections of constant thickness (sections 9 and 10), the sum of the deflections at the joint is less than that at the free edge because of the effect of resisting moments due to the design of the joints. This has been discussed earlier in this report. The effect of the deep groove in the plane-of-weakness joint is apparent if the data for section 6 are compared with those for section 10.

Figure 30 shows a comparison of the deflections of the different corners of the four constant-thickness sections under a given load. The greatest deflection occurs at a completely free or unattached corner. Some reduction in deflection is brought about when the corner is attached on one side by a transverse joint. A still greater reduction is effected when the corner is supported along the other side by a longitudinal joint capable of transferring load. The joints and combinations of joints are different in each of the four sections.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS
1936 AND 1937 FUNDS

AS OF AUGUST 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287				$ 78,130	$ 39,065		$ 460,812	$ 233,406	23.2	$ 4,935,816
Arizona	3,564,709	$ 1,669,709	$ 1,320,304	97.8	489,034	413,183	4.3	175,441	133,165	9.2	1,698,057
Arkansas	4,275,929										4,275,929
California	9,508,671	1,184,591	676,027	37.1	7,560,695	4,335,202	158.6	4,402,977	2,538,563	136.0	1,958,879
Colorado	4,575,144	1,838,205	1,028,873	81.6	2,415,286	1,348,812	76.5	299,605	167,779	10.0	2,029,680
Connecticut	1,582,913				1,087,965	541,780	15.0				1,041,133
Delaware	1,218,750	161,626	90,813	30.3	258,123	129,061	4.1	165,121	82,561	7.7	916,315
Florida	3,315,558	674,678	337,339	23.8	418,048	209,024	12.5	360,093	180,047	10.5	2,589,149
Georgia	6,336,443	223,572	111,786	21.3	1,986,829	962,890	136.2	1,133,409	566,704	56.5	4,695,063
Idaho	3,065,304	663,615	403,280	101.4	2,317,029	1,386,715	168.7	259,551	155,315	19.2	1,119,994
Illinois	10,324,902	1,521,778	760,054	30.5	7,922,269	3,921,760	119.0	2,229,283	1,114,641	40.9	4,528,447
Indiana	6,164,258	2,126,566	1,062,010	74.8	3,925,540	1,962,697	130.6	1,935,480	967,704	63.3	2,171,847
Iowa	6,466,628	2,604,859	1,325,969	247.0	4,131,030	1,955,894	189.4	1,711,268	824,266	33.6	2,360,499
Kansas	6,631,085	1,248,231	623,489	326.9	4,549,805	2,248,455	479.7	1,597,003	798,451	186.2	2,960,690
Kentucky	4,611,955	1,894,397	928,263	128.3	308,333	154,166	14.6	1,230,444	580,941	36.1	2,948,585
Louisiana	3,557,930	957,603	478,802	35.8	1,615,244	807,622	55.4	559,718	279,859	15.3	1,991,648
Maine	2,177,197	1,465,495	731,950	42.8	436,392	218,196	15.9				1,227,051
Maryland	2,050,870				181,230	90,615	3.3	854,879	382,807	10.2	1,577,447
Massachusetts	3,485,364				607,382	303,691	5.1	1,497,728	748,864	10.9	2,432,809
Michigan	7,668,768	2,175,235	1,086,121	87.4	10,169,669	5,082,109	324.2	2,315,650	1,157,825	64.7	342,713
Minnesota	6,849,307	4,594,132	2,114,058	305.9	3,450,991	1,637,247	197.4	1,228,568	614,284	65.8	2,483,718
Mississippi	4,387,636							883,327	441,664	62.2	3,945,972
Missouri	7,601,200	2,360,662	1,177,908	322.1	4,545,043	2,272,521	142.1	3,957,001	2,028,390	282.9	2,122,381
Montana	5,122,333	2,520,163	1,410,907	318.5	1,839,019	1,029,666	100.2	1,107,200	581,730	68.1	2,100,030
Nebraska	5,167,930	1,195,001	597,421	79.8	3,199,641	1,619,183	293.8	1,144,487	558,243	79.6	2,393,083
Nevada	3,189,479	911,306	785,716	153.5	1,030,714	892,289	123.6	129,584	111,275	6.0	1,400,199
New Hampshire	1,218,750	606,373	296,960	19.2	155,703	77,691	3.3	274,045	136,737	3.9	707,362
New Jersey	3,352,469	149,200	74,580	1.1	2,950,263	1,388,601	39.2	805,284	402,642	4.6	1,486,646
New Mexico	3,990,023	1,478,670	898,654	132.1	1,841,118	1,141,839	85.9	740,438	450,334	98.5	1,499,196
New York	12,306,710	602,000	301,000	14.4	12,359,529	6,096,452	208.2	4,821,300	2,399,500	101.1	3,509,758
North Carolina	5,879,466	939,398	469,615	132.9	3,227,109	1,612,159	363.6	282,890	122,648	22.1	3,675,044
North Dakota	3,918,269				191,740	101,206	.1				3,817,063
Ohio	9,131,204	239,940	119,970	5.1	6,009,803	2,968,018	83.2	1,570,772	696,538	8.5	5,346,679
Oklahoma	5,884,927	1,501,063	788,543	57.9	1,631,631	855,167	49.9	1,487,508	781,685	55.6	3,459,532
Oregon	4,089,711	901,250	548,914	31.6	2,798,939	1,621,286	96.6	1,056,471	636,216	34.5	1,283,294
Pennsylvania	10,695,448	1,104,837	552,150	19.9	7,286,311	3,642,120	106.1	3,785,215	1,888,503	49.3	4,612,676
Rhode Island	1,218,750							322,636	161,318	4.8	1,057,432
South Carolina	3,381,337				263,175	120,968	17.4	3,469,273	1,574,750	291.7	1,685,619
South Dakota	4,078,647	628,130	344,404	54.4	776,701	455,082	126.3	32,074	17,586	12.4	3,261,575
Tennessee	5,268,270	1,040,902	519,879	43.3	1,140,268	570,134	43.0	568,099	284,049	24.6	3,894,207
Texas	15,548,821	7,657,787	3,823,655	409.2	6,567,531	3,278,165	365.5	619,455	296,195	5.3	8,150,806
Utah	2,826,960	1,177,497	843,262	89.7	775,547	552,287	43.1	155,383	111,843	7.8	1,319,568
Vermont	1,218,750	753,320	375,994	42.3	769,310	375,311	25.0	372,410	165,898	8.4	301,547
Virginia	4,559,200	697,873	346,582	23.8	2,148,852	1,074,426	86.5	1,884,523	942,261	82.0	2,195,931
Washington	3,904,738	1,097,103	576,992	34.9	3,247,198	1,708,649	135.4	887,556	466,802	38.7	1,152,295
West Virginia	2,716,754	168,656	84,328	7.2	1,206,059	602,518	45.5	294,899	147,449	4.6	1,882,459
Wisconsin	6,090,504	1,104,132	551,489	41.4	5,276,527	2,524,772	197.3	1,438,119	681,611	59.1	2,332,632
Wyoming	3,121,972	2,274,424	1,390,181	250.8	1,085,990	653,047	182.9	514,629	316,042	61.8	762,702
District of Columbia											
Hawaii	1,218,750				467,856	231,167	8.2				987,583
TOTALS	243,750,000	56,354,179	29,958,842	3957.8	126,700,800	65,212,928	5,082.4	55,028,608	27,929,091	2,327.4	120,649,139

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF AUGUST 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115				$ 3,449,243	$ 3,449,243	111.9	$ 512,692	$ 512,692	17.2	$ 189,180
Arizona	2,569,841	$ 1,312,602	$ 1,243,230	91.2	1,669,785	1,217,937	99.5	41,845	19,394	6.1	89,280
Arkansas	3,352,061	1,071,508	1,069,211	80.3	2,048,610	2,031,963	242.8	170,139	169,389	25.5	81,498
California	7,747,928	1,984,574	1,892,616	101.9	5,740,581	5,610,824	145.6	160,841	160,841	1.5	83,647
Colorado	3,395,263	947,101	946,294	64.2	1,128,097	1,128,097	34.0	62,474	62,474	6.0	1,258,398
Connecticut	1,418,709	4,268	3,995		407,166	385,452	2.2	267,235	267,135	3.8	762,128
Delaware	900,310	107,945	107,945	23.3	380,787	380,787	23.8	174,293	145,453	13.6	266,125
Florida	2,597,144	100,691	100,691	8.3	2,144,394	2,126,521	78.2	248,707	248,707	7.3	121,225
Georgia	4,988,967	143,732	143,732	6.1	714,058	714,058	51.6	261,116	261,116	14.1	3,870,062
Idaho	2,222,747	707,401	704,408	64.7	1,523,755	1,486,892	118.5				31,447
Illinois	8,694,009	1,859,451	1,859,119	101.9	6,294,211	6,294,211	338.7	510,557	510,557	26.9	30,121
Indiana	4,941,255	355,983	355,983	9.0	4,653,198	4,232,181	217.9	106,585	106,585	7.8	246,505
Iowa	4,991,664	913,951	865,919	174.0	3,232,114	3,121,849	233.1	1,049,724	987,479	104.2	16,418
Kansas	4,994,975	671,298	671,293	104.9	4,258,188	4,248,377	268.0	75,305	75,305	1.6	
Kentucky	3,726,271	619,600	619,600	111.4	1,848,765	1,848,765	182.8	703,549	703,549	42.0	554,357
Louisiana	2,890,429				2,111,801	1,833,230	118.4	1,011,940	908,770	56.2	148,429
Maine	1,676,799	491,346	491,081	21.1	962,886	961,991	42.3	167,663	167,663	7.4	56,063
Maryland	1,750,738	60,038	60,038	3.0	309,355	309,355	11.9	1,093,042	929,702	26.7	451,643
Massachusetts	3,262,885				934,611	934,611	4.6	508,641	508,641	3.3	1,819,633
Michigan	6,301,414	2,187,200	2,187,200	98.8	3,946,221	3,886,191	185.5	53,000	53,000	3.2	175,023
Minnesota	5,277,145	2,069,500	1,819,484	377.0	3,192,585	2,690,222	448.6	890,267	633,253	80.0	134,186
Mississippi	3,457,552	346,841	346,133	28.2	2,599,971	2,596,545	167.8	156,756	156,756	11.6	358,119
Missouri	6,012,652	2,132,562	2,125,800	546.7	3,248,653	3,197,723	222.6	624,498	621,490	21.0	67,639
Montana	3,676,416	1,931,027	1,931,027	105.3	1,677,010	1,677,010	80.0				68,379
Nebraska	3,870,739	745,501	731,696	97.7	2,445,139	2,413,151	239.6	265,317	265,317	25.8	460,575
Nevada	2,243,074	1,211,443	1,178,417	49.6	787,623	781,080	49.2				283,577
New Hampshire	945,225	181,048	179,415	7.3	474,432	451,535	18.2	119,425	92,522	5.6	221,752
New Jersey	3,129,805				2,158,920	2,158,920	18.4	265,805	251,986	4.6	718,899
New Mexico	2,871,397	1,264,733	1,264,733	109.6	1,048,747	1,048,747	67.9	147,248	147,248	7.2	410,669
New York	11,046,377	1,710,223	1,682,798	16.6	9,171,795	8,787,419	149.5	251,200	251,200	1.8	324,959
North Carolina	4,720,173	510,944	510,944	25.8	3,257,981	3,225,392	232.3	309,740	276,900	15.8	706,937
North Dakota	2,867,245	248,767	248,767	49.7	1,739,288	1,737,001	183.1	606,714	606,714	62.6	274,763
Ohio	7,670,815	508,380	508,380	8.2	4,067,273	4,006,433	106.5	2,136,900	2,026,437	147.6	1,129,564
Oklahoma	4,580,670	608,678	607,067	58.5	2,349,804	2,347,709	216.6	881,471	880,950	102.4	744,944
Oregon	3,038,642	904,981	900,706	39.5	1,850,431	1,761,940	101.1	539,972	261,372	26.2	114,624
Pennsylvania	9,347,797	533,858	508,095	21.0	1,675,411	1,635,478	64.4	1,453,206	1,453,206	71.2	5,751,018
Rhode Island	989,208	232,376	232,376	5.5	747,159	747,159	13.3				9,673
South Carolina	2,702,012	293,927	288,583	34.4	1,767,901	1,699,562	161.0	228,511	228,003	21.1	485,863
South Dakota	2,976,454	753,058	753,058	194.1	1,391,871	1,391,871	208.4	498,803	498,803	60.0	332,722
Tennessee	4,192,460	551,529	551,529	22.2	2,061,306	2,061,306	83.1	679,839	679,839	30.0	899,786
Texas	11,989,350	5,989,725	5,426,804	550.2	6,461,749	5,926,115	545.4	711,913	585,923	22.3	50,508
Utah	2,067,154	695,307	657,917	77.4	1,137,362	1,001,838	86.8	248,525	241,609	11.5	165,790
Vermont	924,306	322,046	304,381	9.8	697,956	576,130	12.0	8,000	8,000		35,795
Virginia	3,652,667	1,398,014	1,356,131	509.0	1,630,684	1,600,408	458.4	477,113	473,528	72.3	222,600
Washington	3,026,161	1,279,513	1,154,226	95.1	1,834,682	1,631,529	64.0	280,130	239,789	5.5	617
West Virginia	2,231,412				1,543,384	1,539,846	59.9	484,209	483,477	20.4	208,090
Wisconsin	4,823,884	1,277,781	1,132,526	115.4	4,030,986	3,549,104	213.7	192,202	136,604	11.6	5,651
Wyoming	2,219,155	501,569	501,563	32.9	1,596,569	1,596,554	106.1				121,038
District of Columbia	949,496	825,733	801,703	7.5	143,498	143,498	.9				4,295
Hawaii	926,033	95,216	82,604	1.3	549,947	541,611	7.6				301,818
TOTALS	195,000,000	42,662,969	41,109,218	4,259.6	115,097,943	110,725,371	6,897.7	19,637,112	18,299,378	1,212.5	24,866,033

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF AUGUST 31, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER			Estimated Total Cost	Works Program Funds	NUMBER			Estimated Total Cost	Works Program Funds	NUMBER			
				Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 94,744	$ 94,744	2			$ 3,202,207	$ 3,202,207	33		1	$ 597,427	$ 597,427	6		10	$ 140,239
Arizona	1,256,099	398,678	394,444	5			650,897	639,452	6			86,220	63,832	1			158,371
Arkansas	3,574,060	635,497	633,117	17	1		1,767,605	1,763,489	25	4		1,035,487	1,033,353	14		29	144,101
California	7,486,362	639,111	626,616	7	4		6,775,110	6,543,321	45	3							316,426
Colorado	2,631,567	684,147	663,147	12			839,851	839,851	11			41,994	41,994		1		1,086,575
Connecticut	1,712,684						68,067	68,067		1		578,069	505,991	3	1		1,138,626
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	284,120	284,120	2	2		1,562,718	1,560,407	16	3		309,257	309,257	9			674,099
Georgia	4,895,949						304,545	304,545	6	1		309,863	309,863	10			4,281,541
Idaho	1,674,479	361,899	361,899	7			754,934	754,934	10	1		8,732	8,732			4	548,914
Illinois	10,307,184	266,677	266,677	8			7,035,438	7,035,438	46	3		788,738	788,738	7			2,216,331
Indiana	5,111,096	4,202	4,202	1			4,866,887	4,743,768	36	11		413,314	89,585			161	273,541
Iowa	5,600,679	253,060	241,000	7	2		3,597,738	3,521,397	71	7		1,238,847	1,233,797	19	1	6	604,485
Kansas	5,246,258	219,579	219,579	3			4,892,292	4,892,292	48	1		134,387	134,387	2		3	
Kentucky	3,672,387	15,290	15,290	1			2,506,758	2,217,026	20			195,636	195,636	2	3		1,244,435
Louisiana	3,213,467						814,208	814,208	7	1		1,594,628	1,550,163	14	3		849,097
Maine	1,426,861	176,568	176,235	5			595,651	595,060	11			406,267	406,267	3		2	249,300
Maryland	2,061,751						408,723	408,723	3	2		1,070,839	1,040,332	4	2	17	612,696
Massachusetts	4,210,833	10,069	10,069	1			1,662,731	1,662,731	12	2		695,455	695,455	6			1,842,577
Michigan	6,765,197	816,125	816,125	10	3		5,332,927	5,288,427	32	4							660,645
Minnesota	5,395,441	555,434	555,434	23		9	3,413,077	3,407,027	53	9	22	610,990	610,990	7		10	821,990
Mississippi	3,241,475	25,677	25,677	2	1		2,048,953	2,048,953	42	2		383,843	383,843	4		1	783,002
Missouri	6,142,153	45,994	45,994	1			5,473,454	5,406,570	39			788,008	665,674	6		2	23,915
Montana	2,722,327	1,164,330	1,164,330	17	4		1,429,652	1,429,652	19	2							128,345
Nebraska	3,556,441	418,265	418,265	13			1,748,130	1,748,130	56	1	5	1,270,689	1,270,689	10		18	119,356
Nevada	887,260	306,096	306,096	7			397,409	397,409	3			205,556	183,755	1		5	
New Hampshire	822,484	34,094	34,094	1			417,861	417,861	2	4	1	12,337	12,337				358,192
New Jersey	3,983,826						1,278,281	1,278,281	7	2		433,620	433,620	5			2,271,925
New Mexico	1,725,286	370,259	370,259	8			629,110	629,110	4	1		575,874	575,874	5			150,043
New York	13,577,189	46,040	46,040		2		9,843,984	9,583,138	32	30		771,355	771,355	1	5		3,176,656
North Carolina	4,823,958	113,110	113,110	1	3		2,171,205	2,171,205	30	7		856,779	840,380	6	4	61	1,699,263
North Dakota	3,207,473	64,305	64,305	2			1,941,898	1,940,898	38			42,034	42,034	1	1		1,160,236
Ohio	8,439,897						2,441,311	2,294,346	16	1		2,572,373	2,485,784	15	4		3,659,767
Oklahoma	5,004,711	806,150	806,150	17	1		1,449,661	1,449,661	20	1		1,202,957	1,202,957	17	2		1,545,943
Oregon	2,334,204	126,698	126,698	1	2		2,258,196	2,133,484	15	4		74,022	74,022	1		2	
Pennsylvania	11,483,613	152,737	121,370	12			4,558,765	4,241,594	35	10		2,256,893	1,919,528	11	5		5,201,120
Rhode Island	699,691	236,879	236,879		1		418,195	417,129	4								45,683
South Carolina	3,059,956	154,754	151,450	3		1	1,210,424	1,202,722	24	5	2	580,239	579,829	11		32	1,125,955
South Dakota	3,249,086	188,494	188,494	10			1,033,679	1,033,679	23			722,742	722,742	14	1	19	1,304,171
Tennessee	3,903,979	28,389	28,389	1		2	527,940	527,940	11	1		1,479,064	1,479,064	18	1	18	1,868,586
Texas	10,855,982	699,096	699,096	18	2		7,463,176	7,456,802	88	11		2,435,354	2,382,315	18	2	150	317,769
Utah	1,230,763	31,147	29,757		1		608,107	608,107	9			305,778	265,000	3			327,899
Vermont	729,857	164,678	164,678	3	3		297,333	295,975	4	2		283,298	221,830	3	1	11	47,375
Virginia	3,774,287	172,632	172,632	11			1,577,240	1,465,216	25	2		828,230	828,230	18	4	11	1,308,209
Washington	3,095,041	276,868	272,068	5	2		2,066,935	2,066,903	11	7	2	510,695	510,695	6	2	5	245,375
West Virginia	2,677,937						426,806	426,806	4	1		908,973	908,973	16	1	4	1,342,157
Wisconsin	5,022,683	310,180	310,180	4			3,789,631	3,789,631	28	6		318,308	286,040	4			636,832
Wyoming	1,360,841	55,366	55,365	2			736,216	736,211	6			205,606	205,605	2			363,660
Dist. of Columbia	410,804						425,564	396,804	3								14,000
Hawaii	453,703						296,218	295,333	3			226,162	158,370	2			
TOTALS	196,000,000	11,407,438	11,314,074	250	34	12	110,161,184	108,271,920	1093	153	33	30,366,939	29,026,344	305	45	581	47,387,662

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Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

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The Taxation of Motor Vehicles in 1932. 35 cents.

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Highway Bond Calculations. 10 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF AUGUST 31, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 14,760,438	$ 8,203,670	$ 3,123,411	739.4	$ 882,512	$ 160,296	$ 722,216	35.9		$ 368,935	2.1	$ 6,167	$ 45,280
Arizona	5,211,960	2,641,935	8,989,767	5,204,513	2,579,241	543.0	12,500		12,500					7,447	50,194
Arkansas	6,748,335	3,428,049	10,908,494	6,635,381	3,303,793	618.4	89,816		89,606	1.5	$ 58,020	18,148	2.8	54,434	16,502
California	15,507,354	7,932,206	30,601,146	15,589,249	7,754,205	760.9	115,025		115,016			820		18,106	62,165
Colorado	6,874,530	3,486,006	11,209,862	6,831,431	3,441,857	639.8								43,099	44,149
Connecticut	2,865,740	1,454,868	4,302,962	2,758,269	1,130,201	71.1	247,903	36,318	182,743	2.9				71,154	141,924
Delaware	1,819,088	923,395	2,676,358	1,818,804	815,188	128.3	53,319		53,319	.5		52,205	1.1	284	2,682
Florida	5,231,834	2,661,343	8,735,667	5,175,534	2,193,368	299.6	389,901		358,854	9.3		15,955	.8	56,300	93,165
Georgia	10,091,185	5,113,491	12,359,292	9,128,990	2,563,026	700.5	1,944,071	599,924	1,278,095	125.2	84,072	77,718	2.0	278,199	1,194,652
Idaho	4,486,249	2,277,486	6,622,657	4,416,568	1,787,381	496.8	429,790		425,402	4.7	42,905	37,043		26,776	27,659
Illinois	17,570,770	8,921,401	24,327,271	16,392,511	7,076,173	665.8	2,906,297	1,075,510	1,724,140	50.0	3,837	27,164	1.0	98,911	93,924
Indiana	10,037,843	5,088,963	14,710,560	9,775,380	4,241,443	450.3	925,856	206,489	690,066	38.0		119,945	.3	55,974	37,509
Iowa	10,055,560	5,113,361	15,361,180	10,055,560	4,708,561	1,218.5	433,921		409,800	8.8					
Kansas	10,089,504	5,117,675	15,349,642	10,003,063	5,021,408	1,131.1	226,121	77,553	60,318	14.4				8,983	35,948
Kentucky	7,517,359	3,818,311	11,584,128	7,448,139	3,303,863	798.1	466,110	59,003	389,509	14.7		9,116	.1	10,217	115,823
Louisiana	5,828,591	2,963,932	8,971,463	5,755,322	2,591,893	249.9	174,054	56,550	117,504	9.5		76,300	6.5	16,720	178,235
Maine	3,369,917	1,711,586	5,222,823	3,337,541	1,657,506	193.1	17,807	10,573	7,234					21,803	46,846
Maryland	3,564,527	1,810,053	4,986,774	3,241,542	751,108	130.5	712,090	240,565	426,560	26.0		380,742	4.9	82,420	251,648
Massachusetts	6,597,100	3,350,474	9,437,847	6,552,734	2,239,899	113.2	846,878		846,878	2.4		91,944	.1	44,366	171,754
Michigan	12,736,227	6,452,568	19,989,169	12,696,114	5,696,115	737.3	660,225		620,798	30.9	40,113		7.8		135,655
Minnesota	10,656,569	5,425,551	16,093,373	10,498,684	4,781,947	1,633.2	427,260	12,666	368,822	16.8	60,099	15,765	6.6	85,120	259,017
Mississippi	6,978,675	3,540,227	12,242,596	6,673,799	2,645,958	704.4	1,081,680	242,417	804,151	39.6	4,437	34,895	.9	58,022	55,223
Missouri	12,180,306	6,173,740	17,090,128	11,408,448	4,629,416	1,433.3	2,364,500	683,247	1,426,150	18.0		108,538	.4	88,611	9,636
Montana	7,439,748	3,769,734	11,571,712	7,324,443	3,574,147	1,033.6	267,308	80,883	186,425	24.7	18,440		.1	15,982	9,163
Nebraska	7,828,961	3,964,364	12,804,172	7,780,128	3,614,698	1,018.4	298,898		254,394	25.0		79,440	8.7	48,833	15,832
Nevada	4,545,917	2,302,356	7,065,206	4,545,917	2,253,348	760.4	25,004		25,004			22,580			1,425
New Hampshire	1,909,839	969,462	2,969,119	1,904,951	931,597	77.7	6,482		6,482					4,888	31,384
New Jersey	6,346,039	3,220,879	7,893,655	6,060,580	1,330,707	81.1	1,949,631		1,509,378	9.7	189,353	175,000	5.1	96,106	205,794
New Mexico	5,792,935	2,941,700	8,750,019	5,743,010	2,800,392	762.8	50,695		38,402	2.3	40,093		3.6	9,831	102,906
New York	22,330,101	11,327,921	38,331,568	21,548,282	9,935,219	807.1	2,200,970	678,700	1,149,599	16.1	50,047	186,135	.7	53,072	56,967
North Carolina	9,522,293	4,840,941	14,523,813	9,029,510	4,269,879	1,329.1	504,733	239,457	265,276	21.4	223,558	200,873	11.1	29,767	104,913
North Dakota	5,804,448	2,938,967	7,913,502	5,599,400	1,620,493	2,064.0	751,739	40,701	658,029	66.2	25,017	169,075	17.5	139,331	491,369
Ohio	15,484,592	7,865,012	23,829,944	15,313,142	6,718,114	770.9	1,099,390	112,165	958,450	24.1		52,706	1.4	59,285	135,742
Oklahoma	9,216,798	4,685,180	14,447,839	9,147,192	4,237,720	804.4	239,170	67,007	172,163	1.8		7,995	.4	2,599	267,302
Oregon	6,106,896	3,097,814	9,795,192	5,976,067	2,916,729	465.4	216,524	64,950	84,161	3.3		30,007		65,879	66,917
Pennsylvania	18,891,004	9,590,788	28,102,637	18,144,308	8,597,505	1,015.6	966,751	448,017	425,140	42.3	31,460	276,282	2.5	267,219	291,861
Rhode Island	1,998,708	1,014,572	3,140,657	1,998,708	1,008,873	89.1						3,806			1,893
South Carolina	5,459,165	2,770,954	7,381,230	5,234,172	1,894,523	590.6	765,168	97,255	645,143	34.5	11,408	59,684	2.1	116,329	171,604
South Dakota	6,011,479	3,047,643	8,844,678	5,775,621	2,493,829	1,515.0	482,823	38,883	443,940	33.1	8,598	42,500	25.0	188,377	67,375
Tennessee	8,492,619	4,302,991	13,099,274	8,492,619	3,585,905	480.2	553,239		553,239	12.5		113,346	9.5		50,500
Texas	24,244,024	12,291,253	37,402,430	23,895,669	11,630,525	2,775.1	872,353	284,494	552,648	10.9		500	7.1	63,861	107,580
Utah	4,194,708	2,132,691	7,191,769	4,160,916	1,991,960	590.6	148,028		108,741	.3	32,292	31,990		1,500	
Vermont	1,867,573	948,007	3,046,595	1,863,531	840,488	137.9	109,523	3,922	90,893	2.4		11,291	.7	121	5,335
Virginia	7,416,757	3,765,387	11,512,618	7,281,756	3,283,352	590.2	206,492	17,720	187,616	27.7	50,432	152,837	12.5	66,848	141,083
Washington	6,115,867	3,106,412	9,366,032	6,098,252	3,022,950	302.7					13,790	59,632	.3	3,825	23,830
West Virginia	4,474,234	2,280,335	6,043,846	4,319,738	1,458,208	205.6	796,912	84,032	656,373	16.9		66,425	.7	70,464	99,329
Wisconsin	9,724,881	4,941,837	15,373,330	9,683,993	4,851,910	619.7	27,006		27,006			37,916		40,888	25,006
Wyoming	4,501,327	2,287,712	6,873,312	4,466,218	2,195,823	1,037.1	16,616	11,729		.7		21,300		23,380	70,589
District of Columbia	1,918,469	973,842	2,740,809	1,909,584	831,090	20.7	120,199		84,699	1.5				8,885	58,053
Hawaii	1,871,062	949,778	2,597,023	1,870,383	169,089	50.6	740,023		736,462	5.2		23,434		679	20,793
TOTALS	394,000,000	200,000,000	609,145,578	384,769,936	170,096,534	34,452.1	28,823,313	5,731,026	20,949,344	831.7	987,971	3,259,987	146.4	2,511,067	5,694,135

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Volume 17, No. 8 October 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE STRUCTURAL DESIGN OF CONCRETE PAVEMENTS

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by **L. W. TELLER**, Senior Engineer of Tests, and **EARL C. SUTHERLAND**, Associate Highway Engineer

PART 4.—A STUDY OF THE STRUCTURAL ACTION OF SEVERAL TYPES OF TRANSVERSE AND LONGITUDINAL JOINT DESIGNS—Concluded[1]

THE SIGNIFICANCE of deflection data in connection with tests of the structural action of joints is a matter about which there seems to be a difference of opinion. A brief discussion of it at this point is pertinent.

The successive changes in curvature of the deflection (or elastic) curve of the slab are values of slope which, if determined with sufficient frequency and precision, may be used to form a slope curve. The changes in curvature of this slope curve, in turn, if determined with sufficient precision, give values of moment, a direct measure of stress. However, the determination of second differences, if these differences are to be significant, must be based upon a precise knowledge of the shape of the basic curve and accurate methods of determination of the changes in curvature.

It has not been found possible in this investigation to measure slab curvature with sufficient precision to permit the use of the deflection data as a basis for estimating absolute or even relative stresses at critical points. A comparison of the relative deflections and of the relative stresses in the vicinity of a load applied on one edge of two typical doweled joints will be shown later in this report and the data presented illustrate the point which has just been made. It is felt that the deflection data have definite value for certain purposes and complete deflection data were obtained in practically all of the tests. Main reliance has been placed upon the strain data, however, for comparisons that would show the relative structural efficiency of the various joints.

JOINTS are needed in concrete pavements for the one purpose of reducing as much as possible the stresses resulting from causes other than applied loads in order that the natural stress resistance of the pavement may be conserved to the greatest possible extent for carrying the loads of traffic.

A joint is potentially a point of structural weakness and may limit the load-carrying capacity of the entire pavement.

Joints are classified by function as:

1. Those designed to provide space in which unrestrained expansion can occur.
2. Those designed for the relief or control of the direct tensile stresses caused by restrained contraction.
3. Those designed to permit warping to occur, thus reducing restraint and controlling the magnitude of the bending stresses developed by restrained warping.

Expansion joints should be provided at no greater intervals than about 100 feet in order to keep the joint openings from becoming excessive.

The spacing of contraction joints will be determined by the permissible unit stress in the concrete. If this is restricted to a low value, which is desirable, contraction joints should be provided at intervals of about 30 feet.

It is indicated that joints to control warping should be spaced at intervals of about 10 feet.

A free edge is a structural weak spot in a slab of uniform thicknesses, and it is necessary to strengthen the joint edges by thickening the slab at this point or by the introduction of some mechanism for transferring part of the applied load across the joint to the adjacent slab.

The doweled transverse joints investigated were quite effective in relieving stresses caused by expansion, contraction, and warping, but they were not particularly effective in controlling load stresses near the joint edge.

The dowel-plate joint tested had merit as a means for load transfer, though it offered more resistance to expansion and contraction than is desirable.

Aggregate interlock as it occurs in weakened-plane joints cannot be depended upon to control load stresses. Even when joints of this type are held closely by bonded steel bars there is wide variation in the critical stress value caused by a given load; therefore, it appears necessary to provide independent means for load transfer in plane-of-weakness joints.

Tongue-and-groove joints held together by bonded steel bars were found to be the most efficient structurally of any of the joints studied. However, modifications of the designs might improve their action.

Before presenting the results of the strain measurements made in connection with the joint tests, it is desired to call attention to two conditions that affect directly the precision of the efficiency values which appear later in this discussion. In the first place, it should be remembered that the tests were made on specimens that were built and tested under field conditions. Certain unexpected variations in the deflection and strain data have consistently appeared when certain sections or certain panels of a given section were tested. These indicate that variations in the strength of the specimen or in the condition of support are present in spite of all the precautions taken to guard against them.

In the second place, the criterion that has been set up as a measure of joint efficiency on the basis of the stress data, while sound in principle, has one practical weakness that should be recognized. Although the critical stress values as determined from the strain measurements are of appreciable magnitude, being generally of the order of 250 to 350 pounds per square inch, when these values are used in the application of the efficiency formula the significant ratio is developed from differences in stress values, both in the numerator and in the denominator of the expression. The differences naturally are of much less magnitude that the stress values themselves and the result is that the ratio of differences is very sensitive to small changes in the stress values from which the differences were obtained. Thus variations in stress determination that are quite unimportant, insofar as the total value of the stress is concerned

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[1] Because of its length, Part 4 is presented in two issues of PUBLIC ROADS. The first installment appeared in the September 1936 issue.

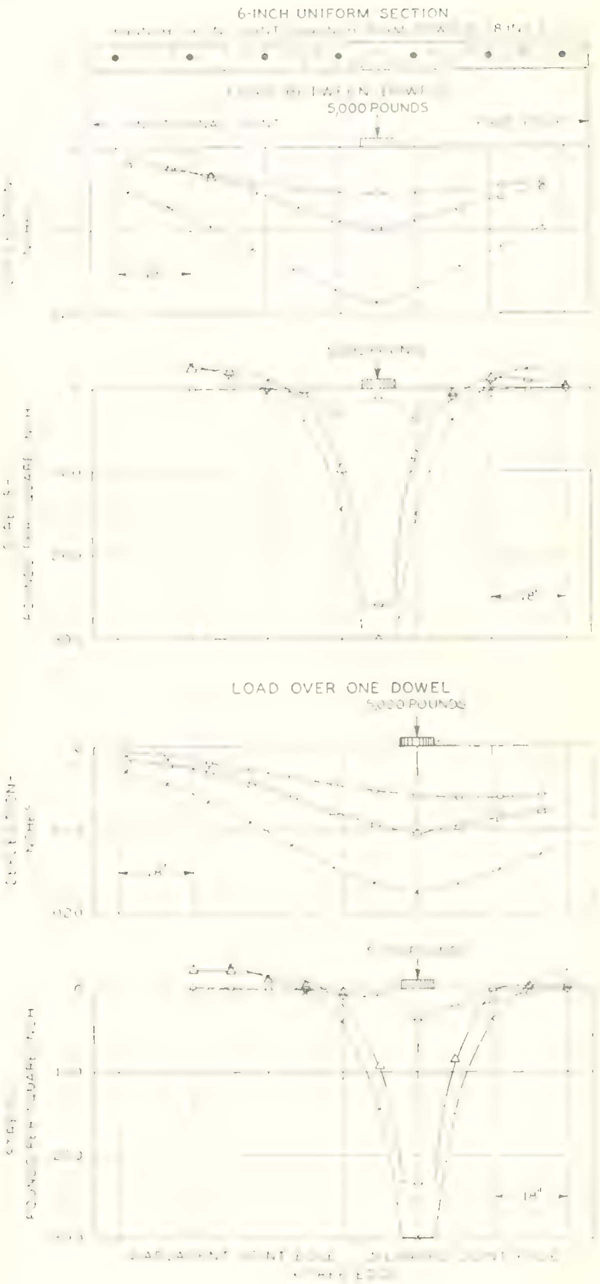

Figure 31.—Deflection and Stress Variation Curves at the Free and Joint Edges of a Typical Transverse Dowel Joint. Stress Values Above the Axis Indicate Tension, and Stress Values Below the Axis Indicate Compression in the Upper Surface of the Slab.

may be sufficient to cause appreciable variations in the ratio by which the structural efficiency is measured.

The stress values used in computing the efficiency values to be presented later were based on averages from tests made at not less than eight comparable points in order to minimize the effect of individual variations in the strain data and are believed to be quite well established. Still, a realization of the manner in which these values were derived will show the necessity for care in the use of individual figures, and will indicate the reasons for certain apparent inconsistencies in the test data.

The tests to determine the effectiveness of the various joints in relieving slab stress were divided into four general groups for convenience in presentation, as follows:

1. Tests to show the character of the stress and deflection variations parallel to the joint.
2. Tests to determine the effect of the transverse joint design on the critical stresses caused by a load acting near a transverse joint, but at a distance from a corner.
3. Tests to determine the effect of the longitudinal joint design on the critical stresses caused by a load acting near a longitudinal joint but at a distance from a corner.
4. Tests to determine the effect of the different joint designs, both transverse and longitudinal, on the critical stresses developed by a load acting on a slab corner.

Mention has already been made of the fact that, with a load acting at the edge of a pavement slab, it has been determined that the highest stress will be found directly under the load in a direction parallel to the edge of the slab. In making the stress measurements for loads applied at joint edges, the stress just mentioned is the critical stress, all others being of less significance. This critical stress was determined for each test at a joint edge and in addition the stress-variation curves were determined through the load position in a direction perpendicular to the joint and for some distance back on each slab.

REDUCTION IN DEFLECTION EXCEEDED REDUCTION IN STRESS

While the stress variation along the edge of the slab is of interest for the comparisons to be made, it was not considered sufficiently important to justify the amount of work that would be involved if these data were to be obtained for every joint. Stress-variation data along the edge were obtained only for one transverse joint with the 18-inch dowel spacing (section 10) and for the longitudinal joint with the 24-inch dowel spacing (section 9). For these two joints data were obtained for a load applied midway between dowels, directly over a dowel, and at a free end. The variations in stress on both the loaded panel and adjacent panel were determined in each case.

The deflection variation and stress variation along the free edge and the two edges of the transverse joint in section 10 are shown in figure 31, while similar data for the longitudinal joint in section 9 are shown in figure 32. The method of grouping makes it possible more easily to make comparisons between the influence of the design on deflection and that on stresses, comparisons that are of particular interest because they show why strain measurements furnish a better basis than deflection measurements for judging the ability of joints to perform their intended function of stress reduction.

If the relations between free-edge deflection and loaded joint-edge deflection are compared and if a similar comparison is made between free-edge stress and that developed at the loaded joint edge, for each of the two joints, it will be found that reductions in deflection and reductions in critical stress are as shown in table 8.

From these values it is apparent that the reduction in load deflection that is obtained with either of these joint designs is not a measure of the reduction to be expected in corresponding critical stress values.

If a similar study is made of the relative deflections and the relative stresses on the two sides of the joint when a load is applied on one of the sides, and ratios

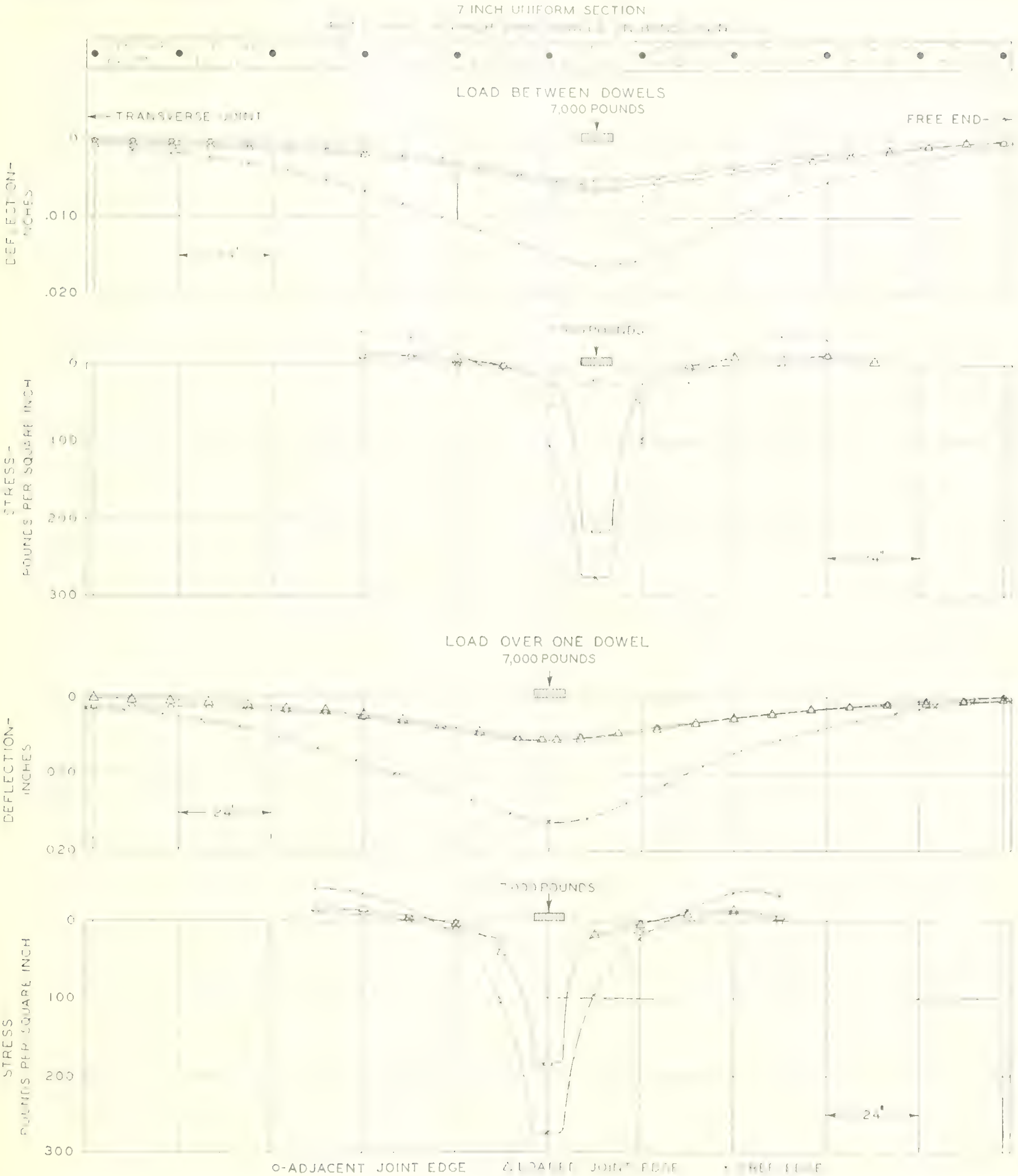

Figure 32.—Deflection and Stress Variation Curves at the Free and Joint Edges of a Typical Longitudinal Dowel Joint. Stress Values Above the Axis Indicate Tension, and Stress Values Below the Axis Indicate Compression in the Upper Surface of the Slab.

are calculated which express the maximum deflection, or stress, in the adjacent edge as a percentage of that found in the edge on which the load was applied, the ratios will have the values shown in table 9.

Again it is evident that the deflection relations are not a usable measure of the stress conditions that accompany them. The point is well illustrated in the case of the longitudinal joint with the load applied directly over a dowel. The deflection curves of the two slab edges are closely comparable, as nearly as can be judged by visual examination (see fig. 32), and the maximum deflection of each is identical. Yet the maximum stress in the loaded edge is more than twice that of the adjacent edge. This is direct evidence of the presence of changes in curvature that are not apparent in the deflection data and for which there is no dependable measure except strain data. Since the reduction of the critical edge stress is one of the chief functions of the joint, this is a very important fact and it has a direct bearing on methods of testing joints for structural efficiency. It emphasizes the impossibility of forming sound judgments regarding the effect of joint designs on stress from deflection data alone. The reasons for this apparent anomaly have already been discussed.

Table 8.—*Comparison of deflection reductions and stress reductions*

	Transverse joint (section 10)	Longitudinal joint (section 9)
	Percent	*Percent*
Load midway between dowels:		
Reduction in maximum deflection	49	60
Reduction in maximum stress	12	23
Load directly over a dowel:		
Reduction in maximum deflection	40	65
Reduction in maximum stress	22	33

Table 9.—*Comparison of deflection ratios and stress ratios between the loaded and adjacent joint edges*

	Transverse joint (section 10)	Longitudinal joint (section 9)
Load midway between dowels:		
Ratio of deflections (adjacent vs. loaded edge)	[illegible]	0.82
Ratio of stresses (adjacent vs. loaded edge)	.14	.23
Load directly over a dowel:		
Ratio of deflections (adjacent vs. loaded edge)	.58	1.00
Ratio of stresses (adjacent vs. loaded edge)	.16	.45

EFFICIENCIES OF VARIOUS TRANSVERSE JOINTS COMPARED FOR LOADS NEAR JOINT EDGES

There are other interesting points brought out in figures 31 and 32. The concentration of the critical stress along these joints is very clearly shown by the stress-variation curves. It will be noted that for these spacings practically all edge stress of any magnitude occurs within a distance of two dowel spacings in the case of a load applied over a dowel and within three dowel spacings for a load applied between dowels. The distribution of the deflection is much greater.

The position of the load with respect to the dowel not only affects the distribution of the stress but also the magnitude of the critical stress, the highest value being observed when the load was midway between the dowels, in each of the joints tested.

In comparing the data in figure 31 with the comparable data in figure 32 the greater stiffness of the longitudinal joint is evident both in the deflection and the stress relations. Because of the presence of the bonded bars a resisting moment is developed during the deflection of the longitudinal joint which accounts for the fact that a deflection reduction of more than 50 percent is obtained. The data indicate that the presence of this resisting moment has no important effect on the stresses in a direction parallel to the joint edge although it does affect the stresses in a direction perpendicular to the joint edge. The effect of the close proximity of the two slab edges in this joint is to make the steel bars more effective as shear units and this causes greater stress reduction, particularly when the load is applied over a dowel. This is shown by the comparative values in tables 8 and 9.

Finally, it is to be noted that for joints such as these, the stresses developed parallel to the joint in the edge of the adjacent slab are relatively quite low in magnitude.

The data which have just been presented serve two important purposes; first, they illustrate the necessity for stress determinations in a study of joint action; and second, they give a general picture of the stress conditions along the edge of the slab which is helpful in connection with the discussion of the other stress data which follow.

Figure 33 shows stress values, as determined from strain measurements in the vicinity of the load applied at the edge of a slab, either at a transverse joint (point G) or at a free edge (point I), for the purpose of studying the structural efficiency of the various joints from the standpoint of their ability to control critical load stresses. The method of placing the loads and of measuring the strains was previously explained in connection with figure 8. The curves connecting the circles show the stress variation along a line perpendicular to the joint and passing through the center of load application. The single values shown by the crosses indicate the maximum values of the stress at the edge of the slab in a direction parallel to the joint. These stresses reach a maximum at the point of load application in those cases where the load is at some distance from a corner.

In figure 8 points G and I are shown on the longitudinal centerline of the panel. Tests were made at these points and at many other points along the transverse joint or free edge and it was found that the edge condition shown by the typical data in figure 33 applies at all points along the edge except within a distance of approximately 3 feet of a corner. Within this distance there is a gradual transition from the edge to the corner condition. For the corner condition the bending stress under the load is negligible and the critical stress is found to be a tensile stress at some distance from the load and along the bisector of the corner angle.

The data in figure 33 show that the most important stress to be controlled by a transverse joint for a loading such as that at point G is that occurring directly under the load and in a direction parallel to the slab edge. Using the method of calculating structural efficiency from stress values that was described earlier in this report, the average values for each of the joints were determined. These values as given in table 10 are not based on the data shown in figure 33 together with the corresponding data for the center of the slab, but upon similar and much more extensive tests in which only the strains occurring directly under the load were measured.

Table 10.—*Efficiencies of the various transverse joints for controlling the stresses caused by loads placed near the joint edges*

Test section no.	Type of joint	Spacing of dowels	Joint opening	Joint efficiency				
				Winter	Summer	Average (various seasons)	Over dowels	Between dowels
		Inches	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Thickened end	None	$\frac{1}{2}$			57		
8	Dowel	36	$\frac{1}{2}$				46	8
6	do	27	$\frac{1}{2}$				31	6
9	do	27	$\frac{3}{4}$				16	20
7	do	18	$\frac{1}{2}$				28	8
10	do	18	$\frac{3}{4}$				40	28
4	Plane of weakness	18		71	66			
3	do	None		4	41			
2	Dowel plate		$\frac{1}{2}$			59		
5	do		$\frac{3}{4}$			66		

The joint in section 1 differs from the others in that there is no connection between the two ends of the

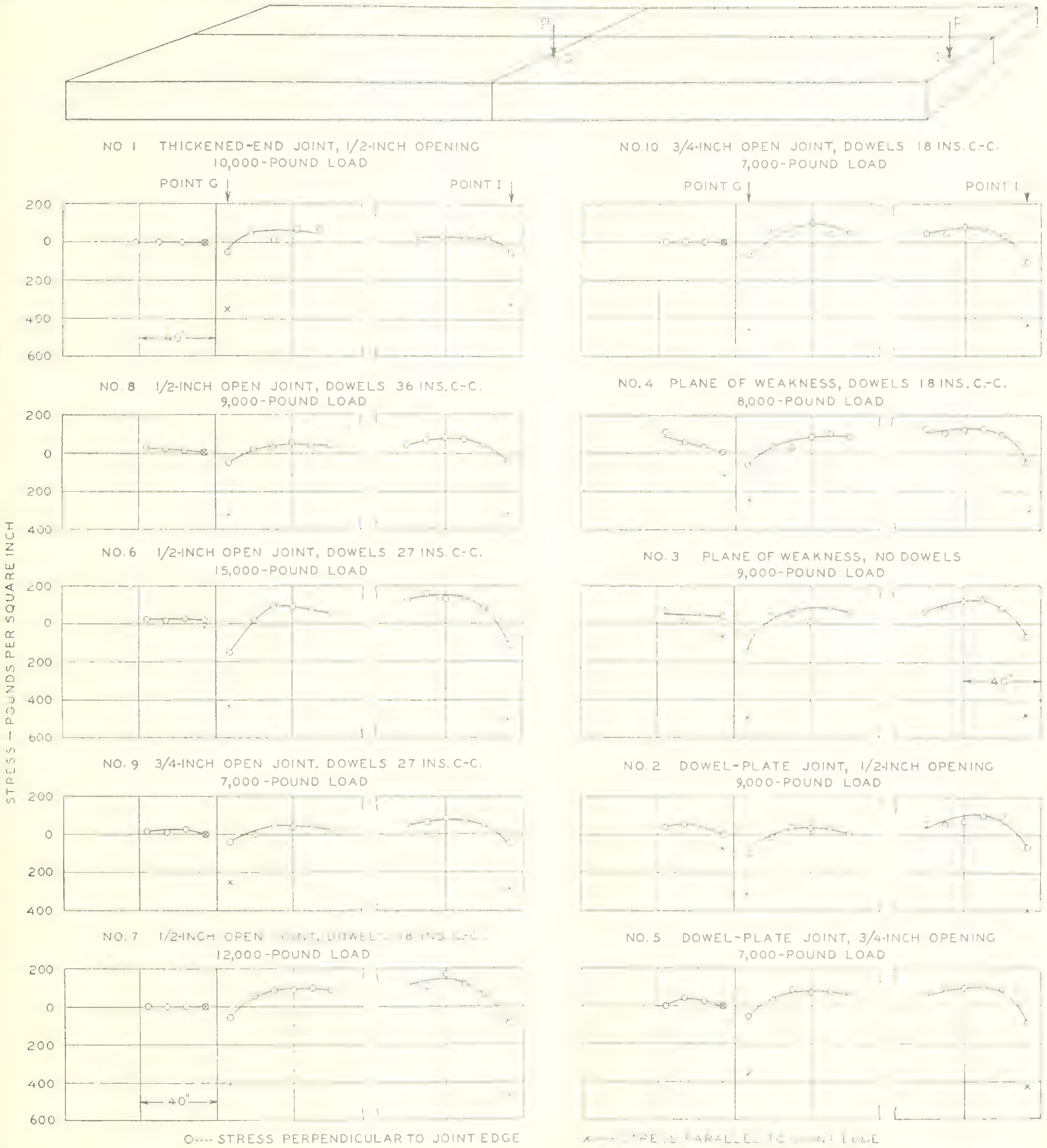

Figure 33.—Comparison of Load Stresses Measured at the Free Edges and at the Transverse Joint Edges of Each of the Sections. Values Above the Axis Indicate Tension, and Values Below the Axis Indicate Compression in the Upper Surface of the Slab.

slabs that form the joint, the edges being strengthened by edge thickening. To make these edges as strong as the center area it is necessary to design the transverse joint edges according to the principles that were described in part 3 of this series of papers.

As indicated in table 10 the doweled joints were tested at points both directly over and midway between dowels. The efficiencies of these joints are generally low at all points, but for loads applied over a dowel the efficiency is often much higher than for loads applied midway between dowels.

EFFICIENCIES OF VARIOUS LONGITUDINAL JOINTS COMPARED FOR LOADS NEAR JOINT EDGES

The dowel spacing was varied in the different sections for the purpose of bringing out the effect of dowel spacing on structural efficiency. It has been learned during the testing of the sections that for edge tests the deflections are so small that the stiffness of the two slab ends, as determined by slab thickness, and the stiffness of the structural connection as determined by the width of the joint opening and by the spacing of the units in the case of the doweled joints, are two very important factors which affect the structural action of the joint. To study the matter of dowel spacing properly, the slabs should be of the same thickness and the joint openings should be the same throughout, leaving the single variable of dowel spacing. This does not mean that the data obtained are of no value but it does explain the apparently inconsistent relations which appear when the data are examined from the standpoint of dowel spacing alone.

The effect of the spacing of the dowels is largely eliminated in the data for loads applied directly over a dowel. The low efficiency for this loading indicates the inadequacy of a ¾-inch dowel installed in this manner for transmitting load across joint openings such as were used in this investigation. The efficiencies are somewhat higher for the ½-inch opening than for the ¾-inch opening although the variation in slab stiffness complicates the data. Some looseness of the dowels may have been present and deflection of the dowels certainly occurred, both of which would lower the efficiency of the joint and to the greatest degree in thick slabs. The matter of dowel spacing will be discussed on a theoretical basis later in this report.

The data in table 10 show a great difference in the efficiency of the weakened-plane joint, without dowels, in winter as compared with summer. The very low efficiency of this joint during the cold season results from opening of the joint as the pavement contracts. It would appear that aggregate interlock cannot be depended upon to transfer load effectively when the pavement is in a contracted condition even on relatively short slabs such as these. For longer slabs the reduction might be still greater, while for shorter slabs it might be expected to be less.

The efficiency of the weakened-plane joint with ¾-inch dowel bars at intervals of 18 inches was found to be high at all seasons of the year.

With the dowel plates, joint openings of one-half inch and three-fourths inch were used to determine the effect of this variable. It will be noted that the joint with the wider opening shows a slightly higher efficiency, contrary to what might be expected. The plate in this case was called upon to deflect a 6-inch slab across a ¾-inch opening, while in the other case a plate of the same size had to deflect a 7-inch slab across a ½-inch opening. The effect of the difference in joint opening is thus obscured by the complicating variable of slab thickness. Both joints appear to be quite efficient in slab edges of this general thickness.

Figure 34 shows typical stress data corresponding to those shown in figure 33 but obtained in tests at longitudinal joints, the loads being applied at points A and B. As stated previously, the stress conditions shown were found to apply at all points along the joint except within approximately 3 feet of a slab corner. The data in this figure indicate again that the critical stress for a load acting near a joint is found directly under the load and in a direction parallel to the slab edge.

The stress data in this figure are shown for both the constant-thickness and the thickened-edge slab. Since the stresses for loads applied at point A are affected by the slab thickness at this point, direct comparison of the stresses at points A and B does not give a true indication of joint efficiency for the thickened-edge slab.

Table 11 contains efficiency values for the longitudinal joints calculated in the same manner as those in table 10 for transverse joints. The stress values used in these computations were average values obtained in tests at a great many points. The loads were placed arbitrarily at points over and at various points between dowels in order that the final averages might be representative of average conditions along a joint of the particular type being tested. The difficulty mentioned in connection with thickened-edge slabs was overcome in the following manner. An average empirical relation was established between the interior and edge stresses on the constant-thickness slabs. This relation was applied to the interior stress of the thickened-edge slabs to determine what the edge stress would have been had the free edge been of the same thickness as the longitudinal joint edge, and this calculated value for free-edge stress was used in the efficiency formula.

TABLE 11.—*Efficiencies of the various longitudinal joints for controlling the stresses caused by loads placed near the joint edges*

Test section no.	Type of joint	Type of tongue	Spacing of dowels [1]	Joint efficiency
			Inches	*Percent*
3	Tongue	Rectangular	60	78
5	do	Triangular	60	75
10	do	Corrugated	60	72
4	do	Rectangular	None	50
9	Butt		24	52
8	do		36	42
2	do		48	51
1	do		60	47
6	Plane of weakness		60	44
7	do		None	39

[1] All dowels across longitudinal joints were fully bonded.

EFFECT OF DOWEL SPACING ON JOINT EFFICIENCY DISCUSSED

All of the tongue-and-groove joints that are held closed by the bonded bars appear to have relatively high efficiencies. The tongue-and-groove joint in section 4 has no dowel bars to hold it together. It was tested in a slightly open condition and it will be noted that, although it has a substantial tongue that is roughly rectangular in shape, a marked reduction in efficiency occurs when the bonded steel is omitted. It appears from this table that the shape of the tongue is of little importance in controlling load stresses so long as the joint edges are held together with bonded steel. The highest efficiency value found was with the joint containing the rectangular tongue and groove, however.

In the four butt-type longitudinal joints, the slab thickness at the joint edge was 7 inches in each case, each joint was separated by tarred felt, and ¾-inch dowels were used throughout. The dowels were deformed bars in bond but their function was to transfer load through shear. In all, 59 load tests were made on these four joints at various times and the loads were applied at various distances from a dowel bar.

From the strain data efficiency values were calculated for each of these tests. These efficiency values were grouped according to the distance between the center of the load and the nearest dowel and each group was averaged, from 4 to 16 values constituting a group. These average group values are shown in figure 35 plotted against the space between the load and the dowel and a curve has been drawn through the values. There is considerable dispersion among the values and the curve as drawn may not be correct as to shape. In

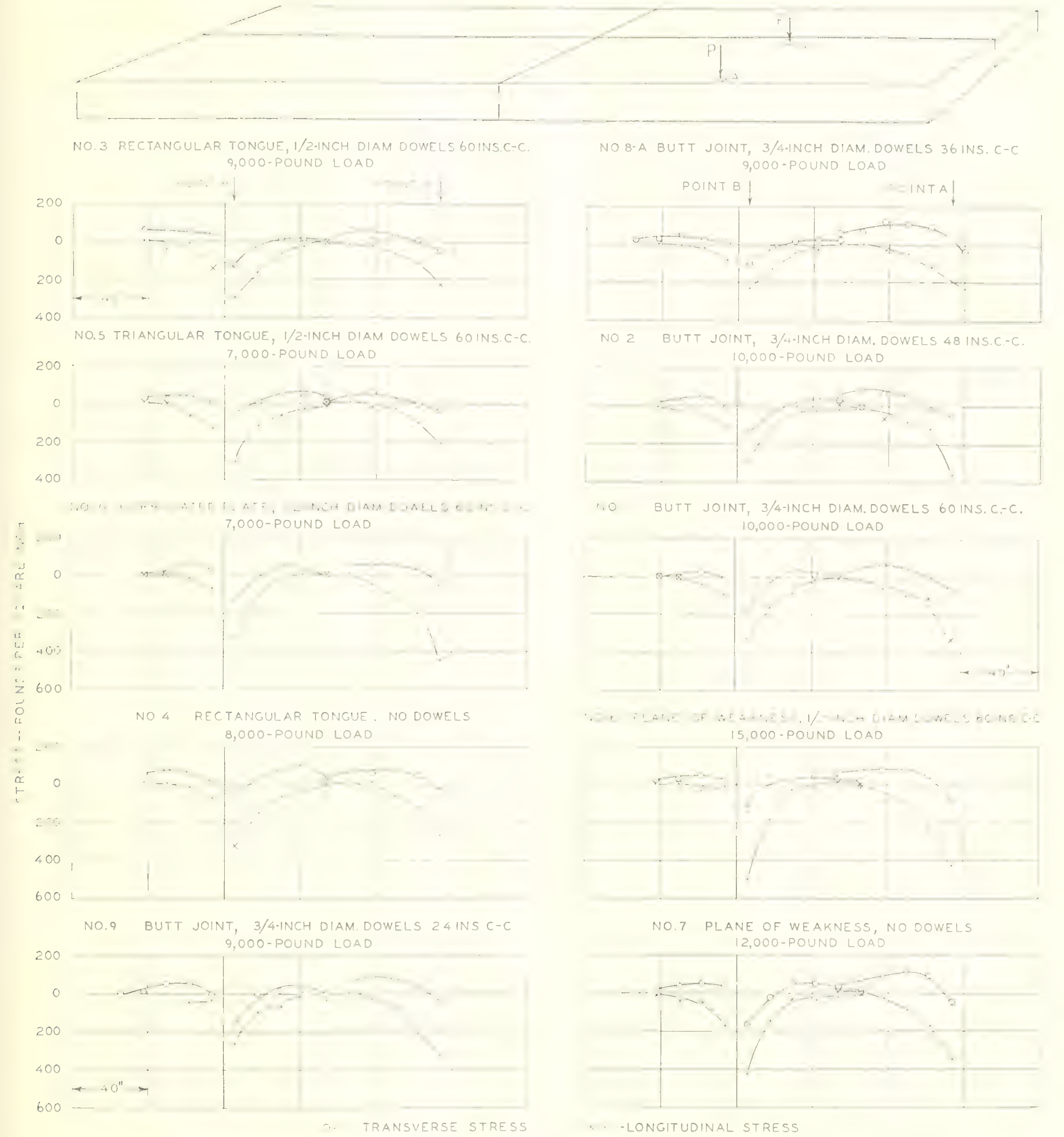

FIGURE 34.—COMPARISON OF LOAD STRESSES MEASURED AT THE FREE EDGES AND AT THE LONGITUDINAL JOINT EDGES OF EACH OF THE SECTIONS. VALUES ABOVE THE AXIS INDICATE TENSION, AND VALUES BELOW THE AXIS INDICATE COMPRESSION IN THE UPPER SURFACE OF THE SLAB.

spite of these deficiencies, it is believed that these data show a useful indication of the effect of dowel spacing on structural efficiency for a joint of such construction that little or no deflection of the load-transfer units can occur.

A comparison of the relative efficiency of the closed, longitudinal, butt joints with the open, transverse, expansion joints having the same dowel spacing shows that the efficiency of a given longitudinal joint is much higher than that of the corresponding transverse joint, particularly for loads applied between dowels. It is obvious that the conditions for load transfer through the dowels in these longitudinal joints are much more favorable than they are in any of the doweled transverse joints.

Neither the butt-type longitudinal joints as a group nor the weakened-plane longitudinal joints were found to have efficiencies comparable to the tongue-and-

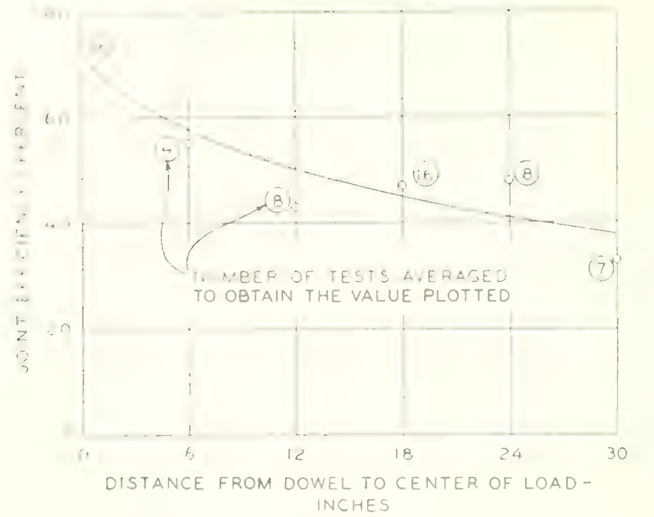

FIGURE 35.—VARIATION IN JOINT EFFICIENCY WITH DISTANCE BETWEEN LOAD AND NEAREST DOWEL (FROM TESTS OF LONGITUDINAL BUTT JOINTS, SECTIONS 1, 2, 8, AND 9).

groove joints in controlling the stresses that occur directly under a load. It is perhaps surprising that the weakened-plane joint that is held closed by bonded steel bars (section 6) should show such low efficiency. It was found in testing these joints that, for loads at certain positions, the indicated joint efficiency was very high, while at other load positions the efficiency was practically zero. It was frequently noted that at a certain point this joint would be efficient when the load was placed on one side of the joint and inefficient when the load was placed directly opposite on the other side of the joint.

The load stresses that occur directly under a load are of a critical magnitude only over a small area and if the stresses are to be controlled by the action of the joint it is necessary that the joint be effective in transferring load in the immediate vicinity of the load. If the functioning of such a joint is dependent upon the interlocking of the broken edges, then the efficiency will depend upon the tightness of the contact and upon the peculiar form of the fractured face directly under the load. If these are favorable the efficiency may be quite high; if they are not then the joint will not reduce the critical stresses. It will be recalled in this connection that the bars in the longitudinal joint were 60 inches apart. In the transverse joint of the same type in which ¾-inch dowels at 18-inch intervals were used, the indicated efficiency was high under all conditions.

EFFECT OF JOINT DESIGN ON CONTROL OF CORNER STRESSES STUDIED

The discussion of the stress data has thus far been confined to the effectiveness of the different joint designs in controlling or reducing the critical stresses that occur when a load is applied at a joint edge but at a distance of 3 feet or more from any corner. With certain slab designs, as, for example, those of constant thickness, a critical stress may also be developed when a heavy load is applied at an unsupported corner. In this case the critical tensile stress is no longer found directly under the load but appears along the bisector of the corner angle in the upper surface of the slab and at some distance from the center of load application. The stress-reducing function of a joint design should extend to the relief of these corner stresses. Since under a given load the slab corner tends to deflect more than the edge, joints that are effective for the edge condition are quite likely to be effective near the slab corner also, but a joint that is quite effective in the corner region may be considerably less effective when the load is applied at an edge but away from a corner.

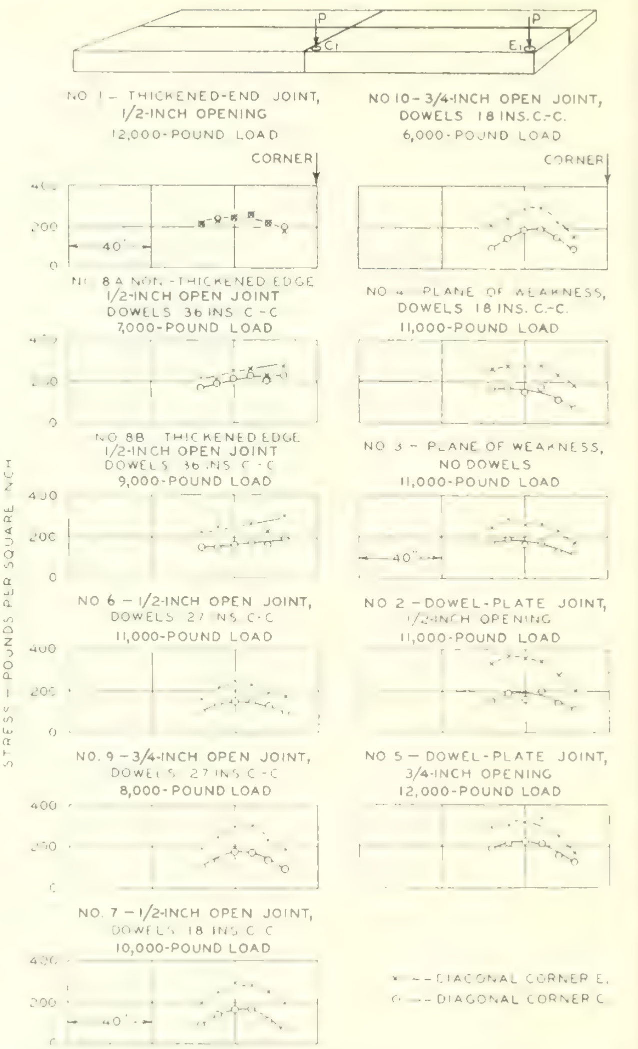

FIGURE 36.—COMPARISON OF THE CRITICAL LOAD STRESSES MEASURED AT THE FREE AND TRANSVERSE JOINT CORNERS. VALUES INDICATE TENSION IN UPPER SURFACE OF SLAB.

Figure 36 shows stress data obtained from the load tests that were made for the purpose of determining the efficiency of the various transverse joints in controlling the critical corner stresses. Figure 37 shows similar data obtained in the same way in tests at the four longitudinal joints that were used in the constant-thickness sections. The reason that data are not given for the other sections has already been discussed.

The stress values shown in these two figures are the averages obtained from tests at four corners in each section. From them stress-reduction values were calculated for each of the joints tested and these are given in table 12. It should be kept in mind that the stress-reduction values shown in the table are not a measure of the general structural efficiency of the different joints but only an indication of the relative ability of the joints to control the critical stresses caused by a load acting at a slab corner. The values are simply the percentage of reduction of the free-corner stress obtained through the use of the various joint constructions.

It will be noted that there are no values in this table for sections 1 and 8. In section 1 the free and joint ends of the slab are of identical construction and the stresses in the free and test joint corners should be of the same magnitude for a given load. Section 8 has a lip-curb design and because of the difficulties in testing caused by the shape of the cross section and the fact that the number of corners available for comparisons are very limited, comparisons were not made.

Table 12.—*Reduction in corner stress caused by transverse and longitudinal joint action*

TRANSVERSE JOINTS

Test section no.	Type of joint	Spacing of dowels	Joint opening	Stress			Reduction in corner stress
				At free corner	At joint corner	Difference	
		Inches	*Inches*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per cent*
1	Thickened end	None	½				
8	Dowel	36	½				
6	do	27	½	247	154	93	38
9	do	27	¾	302	176	126	42
7	do	18	½	295	168	127	43
10	do	18	¾	299	195	104	35
4	Plane of weakness	18		280	172	108	39
3	do	None		283	186	97	34
2	Dowel plate		½	370	203	167	45
5	do		¾	336	225	111	33

LONGITUDINAL JOINTS

Test section no.	Type of joint	Spacing of dowels	Joint opening	At free corner	At joint corner	Difference	Reduction in corner stress
10	Corrugated tongue	60		298	150	148	50
9	Butt	24		302	136	166	55
6	Plane of weakness	60		247	134	113	46
7	do	None		295	180	115	39

Theoretically the maximum amount of load which can be transferred by a joint design can never quite equal 50 percent of that applied to the one side of the joint because of the eccentricity of the point of load application with respect to the joint. Under ideal conditions a transfer of approximately one half of the load to the adjoining slab should result in a corresponding reduction of approximately 50 percent in the critical stress. In the case of a corner this should apply also and as a matter of fact, because of the distributed nature of the bending that accompanies corner deflection, in practice it would be expected to apply even more to corners than to edges. It is probable, therefore, that the actual efficiency of the joints in reducing the critical stresses at corners is approximately double the values listed in table 12.

It was shown previously by the deflection data that it is not possible for a joint to have an indicated efficiency of 100 percent (based upon a comparison of deflections at the free and joint edges) unless the slab is in perfect contact with the subgrade. Since the slabs were unwarped when the corner loadings were applied and thus perfect contact with the subgrade did not exist, it is probable that the percentage of load actually transferred is somewhat more than one might assume from the stress reduction values given in table 12. The reasons for this have been discussed previously in connection with the application of the second method of analysis to the deflection data.

Considering all of the evidence regarding the ability of the various transverse and longitudinal joints to reduce or control the critical stresses resulting from a load applied near a slab corner, it is indicated that practically all of the joints have a relatively high degree of effectiveness.

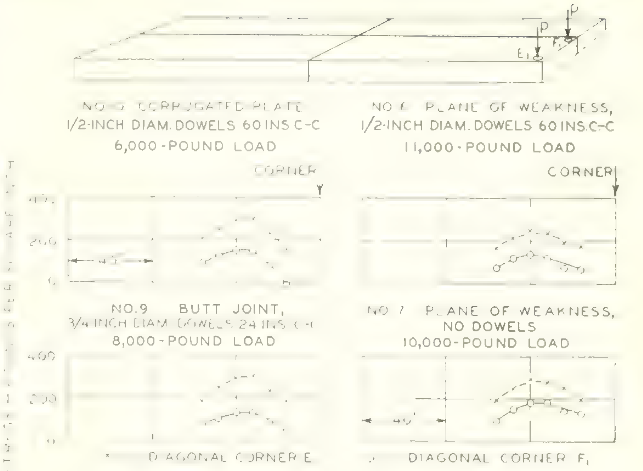

Figure 37.—Comparison of the Critical Load Stresses Measured at the Free and Longitudinal Joint Corners. Values Indicate Tension in Upper Surface of Slab.

EFFECT OF DOWEL SPACING ON JOINT EFFICIENCY DISCUSSED FROM A THEORETICAL STANDPOINT

The transverse joints of the weakened-plane type were tested during the winter when they were in the opened condition. However, the amount of opening resulting from temperature contraction was not large in slabs of this length. This probably explains the fairly high degree of effectiveness shown by the undoweled joint.

The dowel-plate joint having the ½-inch joint opening appears to be somewhat more effective in controlling corner stresses than does the similar joint with the ¾-inch opening. In the case of the doweled joints containing the ¾-inch diameter round bars the effect of joint opening is not definite, probably for the reasons previously discussed. The same is true for indications as to the effect of dowel spacing.

It will be noted that two of the longitudinal joints, on the basis of the corner stress-reduction data, appear to transfer a full half of the load across the joint to the adjacent slab (sections 9 and 10). Section 9 is a 7-inch uniform-thickness slab having a longitudinal joint of the butt type crossed by ¾-inch bonded dowels at 24-inch centers, while section 10 is a 6-inch uniform-thickness section having a longitudinal joint consisting of a corrugated, steel dividing plate and held together with ½-inch bars at 60-inch intervals. Thus, in each, conditions are favorable for the development of a resisting moment and a high degree of load transfer.

The effect of edge thickening in reducing the corner stresses of the thickened-edge slabs is of interest in connection with joint design even though it may not be considered an actual joint design problem. An indication of this effect may be obtained from the stress curves in figure 36 by comparing the stresses at the free corners of thickened-edge slabs with those at the corresponding point of comparable slabs of uniform thickness.

It has been shown that, for a number of reasons, it has not been possible during this investigation to develop from the test data as complete information regarding the proper dowel spacing to control efficiently the stresses that occur directly under a load applied near a

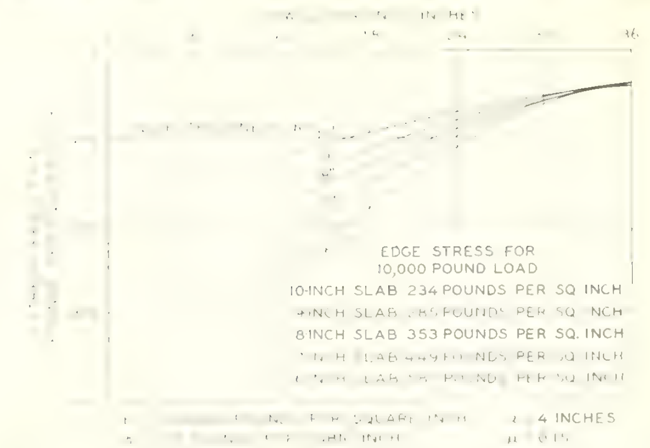

Figure 38. Effect of Dowel Spacing on Reduction of Edge Stress Computed by Westergaard's Exact Method. Relations Shown for a Common Load.

joint as it is desirable to obtain. This was caused in part by the fact that most of the dowel spacings were too great to be effective and in part by the presence of other complicating variables in a number of the tests.

It is believed that a short discussion of the subject from a theoretical standpoint will help to clarify the general relations between load, stress, slab thickness, and dowel spacing.

Making use of the more exact formulas developed by Westergaard in his analysis of this subject,[2] that is, the formulas in which the reactions of the four dowels nearest the load are taken into account, the values that determine the sets of curves shown in figures 38 and 39 were computed. The constants used in the calculations were appropriate to the conditions of the tests at Arlington. In the analysis by Westergaard it was assumed that the dowels were of sufficient stiffness to cause the two sides of the joint to deflect equally. Since dowels do not perform in this ideal manner, it is to be expected that the theoretical stress reductions for given conditions will be greater than those that will be obtained in practice, with joints as they are constructed at the present time.

The stress reductions shown in figure 38 are for a constant load of 10,000 pounds applied on slabs of 6, 7, 8, 9, and 10-inch thicknesses. The stresses theoretically developed in the free edge of each slab by this same load are tabulated in the lower part of this figure.

In figure 39 similar relations are shown, but in this case the magnitude of the applied load was varied in order that the edge stress in each of the various thicknesses of slab would have a constant value of 300 pounds per square inch.

Both of these figures show very clearly that both the amount and the rate of stress reduction increase as the dowel spacing decreases. It is indicated that, even for the ideal condition represented by the basic specification of the analysis, dowels spaced 3 feet or more apart are of little value in reducing slab stresses. When the dowel spacing is 2 feet or less, the dowel reactions become more effective in reducing stress and the analysis shows that if dowels are to be of appreciable value in reducing edge stresses, they must be closely spaced, even when complete rigidity exists in the dowel.

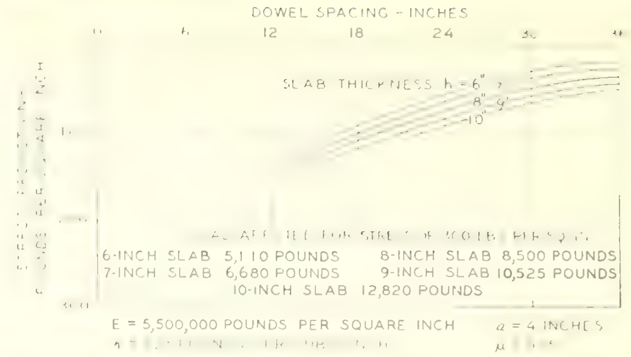

Figure 39. Effect of Dowel Spacing on Reduction of Edge Stress Computed by Westergaard's Exact Method Relations Shown for a Common Edge Stress.

Both theory and experiment show that a load that will produce a critical stress of 300 pounds per square inch in the free edge of a slab will cause a critical stress of slightly less than 200 pounds per square inch when applied in the interior of the slab (provided the slab is of uniform thickness). Thus in this type of slab complete continuity will effect a stress reduction of a little more than 100 pounds per square inch. There are a number of other factors that affect this relation somewhat but the above general statement is approximately true.

Figure 39 shows that, theoretically, in order to accomplish the same reduction with dowels that is obtained by the continuity of the slab (about 100 pounds per square inch), a dowel spacing of approximately 21 inches would be required with a slab 9 inches thick and a spacing of approximately 17 inches with a slab 6 inches thick.

The data presented in this report show that in joints of the types tested, the stress reductions to be expected in joints as actually constructed will fall considerably short of that theoretically possible.

If a doweled joint is to bring about a satisfactory control of edge stresses it would appear that the dowel units will have to provide more shear resistance individually and be spaced much nearer to each other than has been the practice in the past.

MEASUREMENTS MADE OF COMBINED STRESSES AT JOINTS

A pavement slab to be perfectly designed structurally should be so proportioned that a given load, wherever applied, would at all times produce no more than a selected maximum stress at any point. Such a design would make the most economical use of the material and would have no weak spots at which overstressing could occur and failure begin.

The load-carrying capacity of any pavement slab should be indicated by the most critical combinations of load and warping stresses at the different parts of the slab, and the more nearly the ideal design is approached the more readily will these combined stresses attain a common value. There is, however, one consideration that should be mentioned because it affects the generality of application of the statement that was just made. For a load placed at the edge of a slab or at an interior point the load stress is highly localized as has been shown in a number of the figures of this and the preceding papers. When a load is applied on the corner of a slab the distribution of the high stress values is considerably greater. It seems probable, therefore, that a combined stress having a magnitude that would cause a structural failure in the case of a corner loading would not necessarily produce a structural failure when developed under the load in the case of an edge or interior loading. If this is true, a pavement slab should be so designed that the combined load and warping stress at the corner is less than at other parts of the slab.

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[2] Spacing of Dowels, by H. M. Westergaard. Proceedings, Eighth Annual Meeting of the Highway Research Board, 1928, pp. 154–158. [Footnote 12 in the first installment of this paper, Public Roads, September 1936, p. 147, is incorrect, and should refer to the above article.]

Since the interior portion of the slab is inherently the strongest and comprises the greatest area, the object of the design should be to increase the load-carrying capacity of the free and joint edges and of the corners to equal that of the interior of the slab. With this thought in mind table 13 was prepared. The values in the four columns headed "Maximum load stresses" show the magnitudes of the maximum stresses for various positions of a given load, expressed as a percentage of those found for an interior position of this load (point H). The values shown in the columns headed "Warping stresses" are expressed in the same way and are taken from the maximum average warping stresses measured on the two test sections concerned and published in the second report of this series.

The first two columns of each group show data obtained from the thickened-edge slab (sec. 5) while the third and fourth columns contain similar values which apply to three points along the free edge of the 6-inch constant-thickness slab (sec. 10). Other factors being constant, these are the three points where the relations for a constant-thickness slab might be expected to be different from those for a thickened-edge slab.

The warping stresses are applicable only to slabs of the general dimensions tested in this investigation.

TABLE 13.—*Relation of both critical load and warping stresses at points near the free and joint edges of typical slabs compared to the stresses at the interior*

Load at point	Maximum load stresses (upper surface of slab) (percentage of that at point H on each section)				Warping stresses (percentage of that at point H on each section)[1]			
	Section 5		Section 10		Section 5		Section 10	
	Compression	Tension	Compression	Tension	Compression	Tension[2]	Compression	Tension
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
E		71		130	0	11		11
A	109	19	159	45	115		89	
C		18		88	0	11		11
I	159	48			22			
H	100	0			100			
G	120	34			22			
F	84	67			0	11		
B	115	26			89			
D	110	34			0	11		

[1] Warping stresses are for the same points in the upper surface of the slab for which load stresses are given and are for conditions of average maximum warping.

[2] Values are for stresses parallel to the bisector of the corner angle since they are to be combined with the load stresses in that direction.

It will be noted that two load stresses are shown for each point of load application on these two slabs except for points E and C. The values shown in the first column in each case are stresses in the top of the slab directly under the load. These are not shown for points E and C because of their very small magnitude. The second column in each case contains the maximum stresses occurring in the top of the slab at some distance from the area of load application. The efficiency of the longitudinal and the transverse joints naturally affects some of the values given so that relations shown in the table apply to pavements of equivalent cross section and joint efficiency.

The effect of edge thickening on the load and warping stresses at the various points is apparent if the values pertaining to them for section 5 are compared to those for the same points on section 10. Except in those cases where the edge thickening affects the relation, the values shown for points at the free edges and free ends of the sections would apply equally well for joints having little or no structural effectiveness. The effect of the joint design in section 10 in reducing load stresses is reflected in the comparative magnitude of the load-stress values at the corresponding points on the free and joint corners of this constant-thickness slab.

IMPORTANCE OF CONTROLLING LONGITUDINAL WARPING STRESSES EMPHASIZED

There is a small variation in the relation between the load-stress values at the various parts of a pavement slab at different seasons of the year. This will be discussed more thoroughly in the next paper of this series. The relations shown in table 13 for the critical stresses directly under the load are based on data obtained from a great many tests made during the winter months. The values shown for the less critical stresses (those not directly under the load) are based upon less extensive data obtained in tests made at various seasons of the year, although wherever possible the relations shown are averages from several tests.

In order to emphasize the importance of the data just shown and to present them in a more easily assimilated form, table 14 was prepared. In this table the critical combined stresses are given in absolute units and represent stresses that might reasonably be expected to develop in each of the two slabs under the action of a 7,000-pound load and temperature warping of average maximum intensity as determined during the course of this investigation. The values follow directly from the percentages given in the preceding table. In all cases except at the corners the stresses apply to afternoon conditions. For the corners the warping is that which occurs during the night. It was explained in a previous report that it was not possible to determine the corner warping stresses for a thickened-edge slab. For this reason it was necessary to apply to the thickened-edge slab the corner warping

TABLE 14.—*Combined critical load and warping stresses [1] at the midpoint and at points near the free and joint edges of panels of two of the test sections*

Load at point	Load stress[2]		Warping stress		Combined stress		Combined stress (percentage of that at point H)	
	Compression	Tension	Compression	Tension	Compression	Tension	Compression	Tension
	Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Percent*	*Percent*
Section 5:								
E	0	176	0	40	0	216	0	36
A	268		413		681		112	
C		119	0	40		159		26
I	393		80		473		78	
H	247		360		607		100	
G	297		80		377		62	
F	207	165	0	40	207	205	34	34
B	285		320		605		100	
D	272	84	0	40	272	124	45	20
Section 10:								
E		321		40		361		60
A	393		320		713		117	
C		217		40		257		42

[1] Maximum stresses in upper surface of slab.

[2] The load stresses in each section were produced with a 7,000-pound load.

stresses determined from measurements on the corner of a constant-thickness slab. The magnitude of these stresses is so small that this method should introduce no error of consequence.

The warping stresses shown in this table are for slabs 10 feet wide and 20 feet long. It was brought out in the discussion of warping stresses in the second report that, for slabs of the thicknesses used, the maximum warping stresses are approximately as large as they would be for much longer slabs of the same width. The combined stresses shown in table 14 should therefore represent the condition where effective control of warping stress has not been provided.

There was no opportunity in this investigation to make an extensive study of warping stresses on short slabs, but the work that was done indicated that the magnitude of the critical warping stresses would be greatly reduced as the length of the slab was reduced below the 20-foot length used in this series of tests. For short slabs the values of the combined stress will tend to approach the value of the load stress alone.

It is obvious from table 14 that the most important step in the effort to balance the combined stress values is to reduce the warping stress at points A, H, and B. The most effective means for doing this seems to be by shortening the length of the slab. This has already been discussed in connection with cross-section design in the preceding paper and needs no further discussion here. The effect of edge thickening on the load and warping stresses was also discussed in a previous report.

One of the most difficult problems in connection with concrete pavement construction is the control of transverse cracking. It is important to control the critical load stress along a slab edge abutting a longitudinal joint because this stress combines directly with a warping stress that tends naturally to be high. The combined stress, being a longitudinal stress, is in a position to start the formation of a transverse crack if its value becomes excessive. Longitudinal joint designs of high structural efficiency are desirable therefore as an aid in controlling transverse cracking.

JOINTS SHOULD PERMIT FREE FLEXURE OF SLAB EDGES

The longitudinal joints in both sections 5 and 10 were very effective in reducing the stresses under the load and it is apparent from table 14 that, where the warping stresses are controlled, the cross section of a slab having a thickened edge and an efficient longitudinal joint is very well balanced. Because the width of the slab was but one half of its length, the warping stresses at points I and G are much smaller than those at points A and B. This probably explains why longitudinal cracking is seldom observed in slabs having a width of approximately 10 feet.

It is apparently unnecessary, in order to balance the general design of a pavement slab, to reduce the combined stresses at points I and G unless the warping stresses in the longitudinal direction are controlled. Where these stresses are controlled, leaving practically all of the flexural strength of the slab available for carrying load, then it becomes necessary to provide transverse joints that are effective in reducing the stresses directly under the load, when the load is near the joint, in order to make the load-carrying capacity of the slab at point G comparable to that at the interior point H.

The effect of edge thickening and of the joint construction on the stress conditions of the corners E, C, F, and D are well shown by table 14. The warping stresses at the corners are so low that, on the basis of combined stresses, the corners do not appear to be critical points. Because of the distribution of the maximum stress from a load applied at a corner and because of the greater likelihood of impact, weakened subgrade support resulting from the infiltration of water, and possibly other factors, it appears desirable to make the corners of the slab somewhat stronger in relation to the other parts of the slab than would appear to be necessary from the combined stress values in the table.

A comparison of the load stresses occurring along the bisector of the corner angle, for a load acting at point E on each of the two slabs, shows that edge thickening is very effective in reducing these stresses. The effectiveness of joints in controlling these stresses at joint corners was discussed earlier in this paper in connection with table 12.

It is interesting to note that at the inside corners, where the load stresses along the bisector of the corner angle are very low, the stresses directly under the load become relatively high. This is due to the action of the joints causing the slab at point D to behave more in the manner of the interior of the slab. One joint acting effectively will cause the stresses at this point to be distributed as at a free edge, while with both joints effective a stress distribution more like that which exists in the case of an interior loading is created. Thus the position and magnitude of the critical stress at a slab corner depend upon the action of the joint or joints at that corner. Joints that are very effective in controlling the stresses along the bisector of the corner angle may cause a critical stress condition under a load acting near the corner.

It has already been shown that, from the standpoint of reducing warping stresses, free action of the corners at point D is desirable. Such construction would likewise reduce the load stress just discussed and increase slightly the load stress along the bisector of the corner angle of the slab. Therefore, as far as both warping and load stresses are concerned, the joints should be so designed that resisting moments that prevent free flexure are not developed in the joint.

Earlier in this paper it was stated that joints are introduced into concrete pavements for the purpose of controlling certain stresses that are present from causes other than load, and that joints may be classified according to the stresses they are intended to relieve as follows:

1. Expansion joints to control the direct compression stress caused by expansion of the concrete.
2. Contraction joints to control the direct tensile stresses caused by contraction of the concrete.
3. Warping joints to control the bending stresses resulting from restrained warping.

Data developed during the course of this investigation and reported in this and the two preceding papers of this series permit certain general observations to be made and also suggest certain ways in which the joint designs that were tested may be improved.

SPACING OF EXPANSION, CONTRACTION, AND WARPING JOINTS SHOULD BE APPROXIMATELY 100, 30, AND 10 FEET, RESPECTIVELY

The proper spacing of joints is a matter concerning which there has frequently been a wide difference of opinion. The trend of thought as reflected in construction practice during the past was brought out in the historical review at the beginning of this paper. As recently as the December 1932 meeting of the Highway

Research Board, in a paper on the design of joints,[3] R. D. Bradbury stated that: "The proper spacing of transverse joints is largely a matter of judgment based upon experience". In other words, there was available no rational method by which the proper spacing of joints could be determined.

Since joints cost money it has frequently been the policy to install as few joints as possible and to have these of the cheapest type. It is well to remember, however, that the stress reductions accomplished by the introduction of the joint may be worth more in added load-carrying capacity than the cost of the joint installation. This study indicates that frequency of joints can increase the safe load-carrying capacity of a pavement without any increase in slab thickness. Also, frequent joints and the resulting short slab lengths simplify somewhat the structural requirements of transverse joint designs.

It is not the intention to suggest that as a result of this investigation it is now possible to determine rationally the proper spacing of joints under all conditions. Much additional information is needed before this desirable objective can be attained; particularly needed are data on the effects of radically different subgrade conditions and on a number of factors that affect warping stresses. However, the data already obtained make possible several useful generalizations relative to joints. The tests have shown that the distance between expansion joints will not be determined so much by the magnitude of the compressive stresses during expansion as it will by a consideration of the amount of horizontal movement that it is desirable to permit at any one joint. The data presented in the second report[4] show that for ordinary slab lengths the compressive stresses during expansion are relatively quite small, provided no restraint is offered at the slab ends.

Figure 40 has been prepared from data obtained during these studies to give an idea of the average changes in length that occur annually in concrete pavements from changes in the moisture state of the concrete and in the average temperature of the slab (fig. 40–A), and of those that occur daily from temperature change alone (fig. 40–B). The length changes are in inches and apply to a slab 100 feet in length. This graph shows that the rise in temperature from winter to summer caused an expansion of about 0.45 inch in this length of slab. During this same period a loss of moisture occurred which caused a contraction of about 0.15 inch. The net result of the combined annual volume changes was an expansion of about 0.30 inch from winter to summer. The daily changes in length are approximately 0.03 inch in winter and 0.08 inch in summer. The values apply exactly only to climatic conditions and to concrete having volume-change characteristics such as those which existed in these tests. However, there is nothing unusual about either.

It will be recalled that data presented in the second report showed that the test slabs at Arlington are gradually increasing in length. The ultimate extent of this growth cannot be predicted, but after four annual cycles of length change it amounted to approximately 0.17 inch in a 100-foot slab. Such a change when present will have to be cared for in the expansion-joint design.

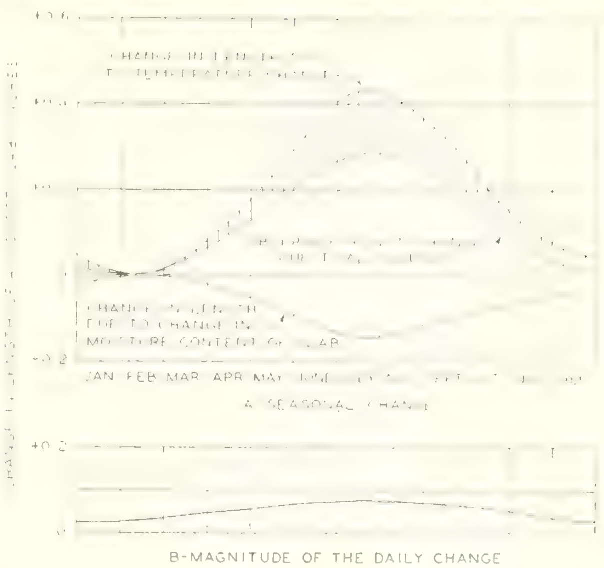

Figure 40.—Average Seasonal and Daily Changes in Length of a 100-Foot Slab Caused by Variations in Temperature and Moisture Content. (Based on Observed Movements.)

In view of the present knowledge on the subject, it seems reasonable to conclude that expansion joints should be provided at no greater than 100-foot intervals in order to keep the joint openings from becoming excessive.

The spacing of contraction joints, unlike that of expansion joints, will be determined by the permissible unit stress in the concrete. If this is restricted to a low value, as is most desirable because of its direct effect on load-carrying capacity, the test data indicate that the contraction-joint interval should be kept quite small, possibly of the general order of 30 feet.

In the second and third papers of the series it was shown that, if the stresses caused by restrained temperature warping are to be properly controlled, the length and width of the slab panels must be kept quite small. Although additional studies should be made to determine what the maximum dimensions should be for various slab thicknesses, the present data indicate that a satisfactory control of warping stresses would ordinarily be obtained if the maximum dimensions of the slab were 10 or 12 feet, indicating that the interval between warping joints should be of the same general order.

EDGE THICKENING AT JOINTS EFFECTIVE ONLY FOR SHORT SLABS

The joint tests in this investigation as originally planned did not include provision for a study of types and arrangement of joints to control warping stresses, and it has not yet been possible to conduct such a study. There are three arrangements that might be considered:

1. Placing joints that will both provide for expansion and relieve contraction stresses at intervals sufficiently small to control warping stress effectively.
2. Placing expansion joints at intervals sufficiently small to relieve contraction stresses and, between the expansion joints, placing joints intended to relieve warping stresses only.
3. Placing expansion joints at the proper intervals, between these placing the contraction joints at the intervals necessary to control tensile stress and, finally, between the contraction joints placing warping joints as frequently as necessary.

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[3] Design of Joints in Concrete Pavements, by R. D. Bradbury, Proceedings 12th Annual Meeting, Highway Research Board, 1932, part I, pp. 105-136.

[4] Structural Design of Concrete Pavements, (see fig. 23 and attendant discussion) Public Roads, vol. 16, no. 9, November 1935.

In deciding which of these different arrangements should be used and to what extent the ideal installation should be approached there are several factors to be taken into consideration:

1. The effectiveness of the proposed joints in reducing the stresses caused by restrainted warping;
2. The efficiency of the joints in reducing the critical stresses caused by a load acting near the joint;
3. The difficulty of maintaining the joints in a properly sealed and smooth condition;
4. Installation difficulties; and
5. Cost.[5]

The strengthening of slab edges at joints has been applied, in practice, to longitudinal joints and to a more limited extent to transverse joints. The application to longitudinal joints appears to have been successful but there has been some criticism of the attempts to use edge thickening at transverse joints because, on certain projects at least, it is reported that transverse cracks have formed within 3 or 4 feet of the transverse joints. The formation of these cracks is attributed in various ways to the presence of the thickened slab end.

In this investigation one of the sections was constructed with thickened ends and this section has been carefully studied over the entire period of the test. It was found that the thickened ends did not increase the resistance of the subgrade to horizontal slab movement because in slabs 20 feet long the subgrade adhered to the concrete and there was little or no sliding of the slab ends. The data obtained indicated no greater tensile stress in this slab, during contraction, than in one built without the thickened ends.

The design of edge thickening for balancing load stresses was described in the third paper of the series, and it was pointed out that edge thickening to be most effective should be limited to relatively short slabs because of the increased warping stresses that tend to develop under certain conditions. These considerations apply with equal force to both longitudinal and transverse joint edges. It is necessary that special care should be taken in the early curing period of such designs to insulate the slabs and prevent the formation of large temperature differentials. In the report of the curing experiments at Arlington[6] some years ago mention was made of transverse cracking which occurred close to the ends of several of the sections that were not protected from the sun's rays during the first 24 hours after placing. This cracking, which was similar in location to that reported on some of the thickened-end pavements, was attributed to high warping stress during the early period of strength development, pointing to the desirability of insulative coverings for curing concrete pavements.

With thickened-end slabs, blocking of the lower portion of the transverse joint with concrete spilled during construction or with solid matter entering after construction is likely to be a serious matter because of the eccentricity of thrust and consequent greatly increased bending moments that may develop near the joint during expansion of the slabs. It is especially necessary, therefore, that, where thickened ends are to be used at transverse joints, care should be taken to insure that there is space for free expansion at all times.

IMPROVEMENTS IN DESIGN OF DOWELED JOINTS RECOMMENDED

The doweled transverse joints tested were found to be effective in the two functions of permitting unrestrained expansion and contraction and in allowing the slab ends to warp freely. These joints as constructed in this investigation were not satisfactory, however, so far as their ability to reduce the stresses caused by load is concerned. For loads acting at joint corners fair reductions in the critical stress were obtained, and the same is true for loads applied directly over dowels, but for other conditions of loading the stress reductions generally were much smaller than is desirable.

Attempts to improve the doweled joint designs should begin with efforts to increase their effectiveness in reducing the critical stresses caused by a load placed near the joint but at a distance from a corner.

It is indicated that the doweled transverse joints as built and tested in this investigation have the following weaknesses:

1. The individual units were too widely spaced.
2. The individual units were not stiff enough effectively to transfer loads of the magnitude and under the conditions involved.
3. It is difficult to obtain complete and perfect embedment of a dowel bar.
4. Even if perfect embedment were obtained the unit bearing stress on the concrete is apt to be excessive when heavy loads are applied on one side of the joint.

The closest dowel spacing tested was 18 inches and it is evident from the data that, for dowel size, joint openings, slab thicknesses, and loads of the same general order as were used in the tests, this spacing is too great. It is not possible to state, from the test data, what the proper spacing should be in order to make this joint highly effective in relieving the important edge stresses. The minimum spacing of dowels will be determined by the magnitude of the critical stress caused by a load applied at the joint edge at a distance from a corner. If the spacing is close enough to control this stress satisfactorily, the stress conditions for a load acting at the slab corner will also be satisfactorily controlled, so long as no resisting moment is allowed to develop in the joint itself.

It has been shown previously by some of the load-deflection measurements that one very important cause of the low efficiency of the doweled joints in controlling load stresses is the lack of stiffness in the dowel itself. This suggests that the size or shape of the dowel should be changed, that the joint opening should be decreased, or that the bearing conditions of the dowel in the slab should be improved in order to increase the resistance to bending of the unit. Any great increase in the bending resistance of the joint is undesirable because it reduces the ability of the joint to relieve warping stress, one of its most important functions. It is necessary, therefore, to proceed cautiously with any changes tending to increase joint stiffness.

Tests made for the purpose indicated that, when the concrete around the dowel is placed with great care, little or no play between the dowel and the concrete existed. It is difficult to be certain that this condition will always be obtained in construction. Indeed, it is to be expected that it will not, unless unusual attention is given to it. Furthermore, although no thorough study has been made of the effect of continued service on the seating of dowels, there is good reason to believe that such usage tends to develop looseness.

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[5] For [illegible] of current costs and other considerations, the reader is referred to [illegible] Development in Transverse Joints and Fillers in Concrete Pavements [illegible], presented before a meeting of the Association of State Highway [illegible] of the North Atlantic States, Baltimore, Md., Feb. 14, 1935 [illegible] Vol. 14, No. 2, April 1935, for a similar discussion by the same author.

[6] The Arlington Curing Experiments, by L. W. Teller and H. L. Bosley, PUBLIC ROADS, Vol. 10, No. 12, February 1930, pp. 218-219.

Under the small deflections of pavement slabs, continued good bearing is essential if the dowels are to maintain their original effectiveness. This suggests that some bearing other than that of the concrete should be provided in order to make the bearing conditions more effective and permanent. What the best form for such a device should be cannot be determined without more tests. Certainly there are problems connected with its design which will have to be worked out, and this is true also for the other possibilities that have been discussed.

The doweled joint is not an ideal type and probably will never approach closely to its theoretical efficiency, but there is little doubt that it can be improved considerably by correcting its recognized weaknesses. From the information at present available it seems probable that the greatest all-around effectiveness in a joint of this type will be had with dowel members that are not too stiff, that are spaced closely in a joint that is opened as little as possible, and with good bearing of the dowels in the slabs insured through the installation of an effective dowel seat.

FURTHER INFORMATION NEEDED ON ACTION OF VARIOUS JOINTS

The tests made with the limited number of dowel-plate joints included in this investigation indicate that this type is quite effective in relieving warping stress and in reducing the critical stresses caused by loads acting near the joints. The continuous plate, as used in these tests, appears to control the stresses directly under a load more effectively than round dowels at any of the spacings tested.

The tests showed that the dowel-plate joints offer more resistance to expansion and contraction of the slab than do the joints containing the round dowels regardless of their spacing. The concrete was carefully placed around the dowel-plate covers at the time of construction. Because of the small space between the plate and the subgrade special manipulation was necessary but a satisfactory installation was obtained. There can be little doubt that the same tight gripping of the plate in its socket, which caused the resistance to slab movement just mentioned, is responsible for the effectiveness of the construction in reducing the edge stress.

Only two dowel-plate joints were studied and the information developed leaves unanswered a number of questions. For example, it is desirable to know what width and thickness of dowel plate will be most generally effective in slabs of different thickness. Also it is desirable that means be developed for effectively sealing the joint or by other means reducing corrosion of the dowel plate to a minimum.

The data indicate that the dowel-plate joint has considerable merit and that a more thorough study of its possibilities is warranted. Determination of its effectiveness after having been in service for some time would seem to be particularly important.

This investigation revealed that the weakened-plane tranverse joint without dowels is not effective in reducing the stresses directly under a load acting near the joint when the joint is open and may not be effective when the joint is tightly closed. It appears to be fairly effective in reducing corner stresses when closed but may become very ineffective when open. The fact that these joints sometimes do not function effectively though tightly closed is apparent due to an inclined fracture. The character of the support varies from side to side of the joint and from point to point along each side, being effective in some places and quite ineffective in others.

FIGURE 41.—PLANE-OF-WEAKNESS JOINTS DESIGNED TO PERMIT FREE WARPING.

The weakened-plane transverse joint with dowel bars spaced 18 inches apart was found to be much more consistent in its behavior and fairly efficient in reducing corner stresses and stresses directly under the load. There is little to indicate that aggregate interlock can be depended upon to control the critical stresses caused by load under any conditions and this applies to the longitudinal as well as the transverse plane-of-weakness joints. It appears that to control the stresses effectively and thus strengthen the joint edge, the same type and character of edge support will be necessary with a weakened plane of the type tested as would be required with butt joints.

The weakened-plane joint will control warping stresses effectively if it is so designed that a resisting moment within the joint cannot be developed. In a warping joint, prevention of the development of a resisting moment may be accomplished in any one of three ways: (1) By preventing the steel dowels from taking tension through a destruction of bond on one or both halves of the dowel; (2) by preventing the concrete from developing compression by separating the two slab ends; or (3) by greatly reducing the length of the moment arm so that for a given joint deflection the magnitude of the resisting moment is greatly reduced even though the steel dowels take tension and the concrete surfaces are tightly interlocked.

Weakened-plane joints designed to prevent the development of large resisting moments during warping are shown in figure 41. It should be recalled that the downward warping of the slab edges normally exceeds the upward warping by a considerable degree and, further, that under the conditions that cause upward warping of the slab edges, the concrete is in a contracted state and the joints are opened, the dowels being without bond.

In this class only the longitudinal joints of sections 3, 4, 5, and 10 are considered. None of these was intended as an expansion joint and none of the designs included in this group could be expected to function satisfactorily as an expansion joint because the shape of the interlocking elements is such that separation horizontally is in each case accompanied by a separation vertically that would prevent effective load transfer by the joint.

Of the four joints considered, only that in section 4 could be expected to relieve direct tensile stress caused by slab contraction. This joint, it will be recalled, had a trapezoidal tongue roughly rectangular in shape although there is appreciable slope to the upper and lower faces. No dowels or tie bars cross the joint. At the time the load tests were made the joint was opened slightly so that the stress values obtained probably indicate the efficiency under critical conditions.

The joint was found to be fairly effective in reducing the critical corner stress, but, for loads applied at the joint edge at a distance from the corner, the efficiency

FIGURE 42.—RELATIVE DISPLACEMENTS OF THE VARIOUS PARTS OF TONGUE-AND-GROOVE JOINTS DURING DOWNWARD WARPING.

FIGURE 43.—RELATIVE DISPLACEMENTS OF THE VARIOUS PARTS OF TWO TRIANGULAR TONGUE-AND-GROOVE JOINTS DURING DOWNWARD WARPING.

in reducing the critical stress is much less than it was found to be for the same type of joint held closed by bonded steel. This undoubtedly results from the tendency for the tongue to loosen as it is withdrawn from the groove and indicates the necessity for designing a different shape of tongue if this general type is to be considered as a contraction joint. Although a perfectly rectangular tongue section would probably be the most effective design for controlling load stresses, it would restrain warping and, probably to a lesser extent, free horizontal movement. It appears necessary, therefore, that the shape of the tongue and groove should depart from the perfectly rectangular form.

ACTION OF TONGUE-AND-GROOVE JOINTS DURING SLAB WARPING DESCRIBED

Figure 42 illustrates a simple method for determining graphically the relative movements of the two sides of three designs of tongue-and-groove joints during warping of the slab ends. It is assumed that in each design the ends of the two slabs both above and below the tongue and groove have been relieved by inclining the face of the edge slightly as shown in the section. The point of contact and probable center of rotation would be just above the tongue during downward warping and just below the tongue during upward warping, approximately as shown in the figure.

In the first design (fig. 42–A) the upper and lower faces of the tongue are parallel. It is apparent that as warping occurs the tongue will bind in the groove and will not be able to take the position that it would assume if unrestrained warping were to be permitted. Restraint is developed that will cause undesirable warping stress in the slabs near the joints and high local stresses in the elements of the joint itself.

In the second design (fig. 42–B) there is considerable slope to both the upper and lower faces of the tongue. When warping occurs there is a tendency for these faces of the tongue and groove to separate, depriving the joint of its ability to transfer load during small deflections.

Figure 42–C shows a section modified in accordance with the preceding discussion. The upper and lower surfaces of the tongue have been shaped so that neither excessive bearing pressures nor loss of contact should occur during slab warping. It is emphasized that this design is only a suggested application of the results of these tests and should be given an experimental verification before being recommended as a design suitable for contraction and warping joints.

Figure 43 is a similar study of the triangular shape for tongue-and-groove joints. For the assumed conditions it appears that if the depth of the tongue "*d*" is greater than approximately one-half of its height "*h*", warping will cause high local bearing stress near the end of the tongue (fig. 43–A), while if the depth is less than about one-half the height, separation will occur as the slabs bend. This analysis indicates and the test data show that the triangular tongue and groove is likely to be less satisfactory during contraction or warping than the modified rectangular forms.

For the reasons just discussed in connection with the joints shown in figures 42 and 43, it is apparent that the corrugated plate used in the longitudinal joint in section 10 would be unsatisfactory as a contraction joint and would be less satisfactory than the modified rectangular tongue as a joint for the relief of warping stress. It is probable, however, that because of the many possible points of contact and lack of sharp corners, it will not be so likely to develop high local bearing stress as either the perfectly rectangular tongue or the deep triangular shape during warping.

The tongue-and-groove types, as a class, have been shown to be quite effective when constructed and tested in the manner described. The preceding discussion was intended to bring out the weak points of the designs in order that means may be found for improvements that will add to both the structural effectiveness and the durability of the joints.

The doweled transverse joints are not considered to be butt-type joints because of the wide joint opening. Only the four longitudinal butt-type joints found in sections 1, 2, 8, and 9 will be discussed. They are primarily joints for the relief of warping stress, being unable to function either as expansion or contraction joints because of the bonded dowels. Four different dowel spacings were used as was shown in figure 7. As stated earlier, it was not possible to determine the effectiveness of all of these joints in reducing corner stresses because a number of them were in thickened-edge slabs, but all of them were tested to determine their efficiency in reducing the stresses directly under the load when the load was applied along the edge but away from a corner. The results of these tests have been shown in table 11 and in figure 34 of this paper. The one joint of this type on which it was possible to make such determinations was found to be effective in reducing critical stresses for the corner loading.

PREVENTION OF RESISTING MOMENT NECESSARY IN DESIGN OF BUTT-TYPE JOINTS

So far as dowel spacing is concerned, butt-type longitudinal joints can be made more effective in their function of controlling load stress by the close spacing of dowels in the same manner as expansion joints. In the matter of dowel stiffness the situation is different, however, because the small opening between slabs greatly reduces dowel flexure, as was shown by all of the deflection data for these joints. It is probable that in longitudinal joints of the butt type the need for better bearing for the dowels is as great as in the doweled expansion joint and that the same general type of bearing should be provided.

If restraint to warping is to be eliminated, it is necessary to make some provision for preventing the edges of the abutting slabs from being pressed together during warping, particularly near the upper and lower surfaces of the slabs. This can be accomplished by the introduction of a compressible layer between the edges during construction, as was done in the case of the test slabs, or perhaps better by so shaping the slab edges that the necessary clearance will be provided in a manner similar to that suggested in connection with the plane-of-weakness joints.

The amount of steel that must be placed in a warping joint in order to hold the slab edges together depends primarily upon the amount of resistance to horizontal movement to be overcome and upon the unit stress permissible in the steel.

In joints that contain bonded steel the use of designs that do not permit large resisting moments to develop in the joint is desirable for two reasons. In the first place, the prevention of these moments relieves the concrete of the stresses arising from warping restraint and thus conserves its strength for load-carrying purposes. In the second place, the prevention of these moments will further protect the pavement structure by preventing the steel in the bonded dowels or tie-bars from being overstressed in tension.

The amount of bonded steel likely to be used across a longitudinal joint will be sufficient to prevent large separations of the two slab edges during contraction, but will be insufficient to prevent some separation of the slab edges resulting from angular change during warping. Indeed it is desirable that the amount of restraint to these rotational movements during warping be kept as small as possible. A given temperature differential in the pavement tends to cause a given rotational movement of the abutting faces at the joint. If this rotation brings the concrete into tight contact, it develops compression in the concrete and this tends to separate the slab edges by a certain amount at the plane of the steel. For a given percentage of steel taking tension, the magnitude of the tensile stress developed in the steel when this given separation occurs will depend directly upon the effective length of the steel that is yielding under the tension.

If the bond is deliberately prevented for a few inches in the center of the bar, as for example, with a coating of bitumen, more bar length would be available to yield under the given force. The unit deformation in the critical section of the bar would be smaller, and the stress would be correspondingly reduced. The net result would be less restraint in the joint for a given temperature differential and a given percentage of steel. Furthermore, such a coating would protect from corrosion the most vulnerable part of the bar.[7]

With designs that will permit resisting moments to develop during warping it is not possible to calculate the amount of steel required, but with these moments eliminated the calculation becomes a relatively simple matter.

In the discussion of joints in this article there has been presented (1) a brief history of joint development up to the time at which this investigation was planned, (2) a description of the joints that were studied and of the manner in which they were tested; (3) a presentation and discussion of all pertinent data bearing upon the ability of the various joint designs to relieve the stresses caused by expansion, contraction, restrained warping, and applied load; and (4) a discussion of certain improvements in design suggested by the results of the tests.

CONCLUSIONS

The following statements give what are believed to be the most important conclusions to be drawn as a result of this study:

1. Joints are installed in concrete pavements for the purpose of conserving the natural flexural strength of the slab for its primary function of carrying loads. This is accomplished through the relief and control of the stresses caused by expansion, contraction, and restrained warping. Joints in concrete pavements should therefore be so designed and so spaced as to permit the entire pavement to expand, contract, and warp with a minimum of restraint.

2. While the proper spacing of joints to accomplish this end was not definitely determined by this investigation, it is indicated that joints to control warping should be spaced at intervals of the general order of 10 feet, that expansion will be satisfactorily cared for by suitable joints at intervals of approximately 100 feet, and that contraction joints should be installed at some lesser interval, the length of which must be such that the direct tensile stresses in the concrete are definitely limited to low values. Data presented in the second report of this series indicate that under the conditions of these tests a slab length of the order of 30 feet would accomplish this.

3. Since a free edge is a structural weak spot in a slab of uniform thickness, it is necessary to strengthen the joint edges by thickening the slab at this point or by the introduction of some mechanism for transferring a part of the applied load across the joint to the adjacent slab. Otherwise, the strength of the joint edge will determine the load-carrying capacity of the pavement.

4. The structural effectiveness of a joint design is measured by its ability to reduce the critical edge stress to a value equal to the critical stress which exists in the interior area of the slab.

5. The most critical stress caused by a load applied at a joint but away from a corner is that directly under the load in a direction parallel to the joint. It is especially desirable to control these stresses along a

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[7] The idea of coating the mid section of bonded bars with bitumen was suggested by Mr. Bengt Friberg.

longitudinal joint so as to limit the combined load and warping stress to a value that will be unlikely to cause transverse cracking.

6. The most critical stress caused by a load applied at the free corner of a slab of constant thickness is a tensile stress along the bisector of the corner angle and at some distance from the center of load application. Edge thickening reduces this critical stress considerably and at interior corners the action of the longitudinal and transverse joints frequently reduces the critical corner stress to relatively low values.

7. There is nothing in the results of these tests to indicate that edge thickening cannot be applied to the transverse edges of concrete pavement slabs with as much success as to the longitudinal edges. If the full benefits of edge thickening are to be obtained in either case, the slabs must be short.

8. The doweled transverse joints tested in this investigation were found to be quite effective in relieving the stresses caused by expansion, contraction, and warping. They were not particularly effective, however, in controlling the critical stress caused by a load applied near the joint edge.

9. The tests indicate that doweled joints as they are usually designed are deficient in two important respects:

a. The individual units are not sufficiently close together to control effectively the stress developed directly under the load.

b. For joint openings such as are usually employed in expansion joints, the individual dowels are not sufficiently stiff to transfer load effectively. Increasing the stiffness of the dowels will result in an undesirable increase in the restraint to warping offered by the joint and for this reason should not be carried too far.

10. The continuous plate key or dowel plate as used in these tests appears to have considerable merit as a means for load transfer. The joint as built for the tests offers more resistance to expansion and contraction than is desirable and for this and other reasons it is believed that a further study of the type should be made.

11. Aggregate interlock as it occurs in the weakened-plane joints cannot be depended upon to control load stresses. Even when joints of this type are held closed by bonded steel bars there is a wide variation in the value of the critical stress caused by a given load, from side to side of the joint and from point to point along it. For this reason it appears necessary to provide independent means for load transfer in plane-of-weakness joints.

12. The joints of the tongue-and-groove type that were held closed by bonded steel bars were found to be the most efficient structurally of any of those tested. It appears, however, that certain modifications of the designs might improve their action by permitting the slabs to warp more freely and at the same time maintaining the bearing between the tongue and the groove.

13. It was shown in the second report of this series that over a considerable period of time there may be a permanent increase in the length of the pavement slab. In designing the expansion joints for a pavement, consideration should be given to this possibility and some allowance made for it.

PUBLICATION ON HIGHWAY BONDS AVAILABLE

Highway Bond Calculations, by Laurence I. Hewes and James W. Glover, has recently been published by the United States Department of Agriculture. This publication consists of selected sections of Department Bulletin 136, Highway Bonds, as published in 1917, the supply of which has been exhausted for some years.

Sinking-fund, serial, and annuity bonds are described in detail and their relative merits are compared. Definitions of the terms involved are given, together with explanations and derivations of essential formulas. Numerous examples of typical problems and their solutions are presented. Several tables to seven decimal places for 60 intervals and 14 interest rates are included, making the publication a useful reference in making bond calculations.

Copies of Highway Bond Calculations may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents each.

HIGHWAY RESEARCH BOARD TO MEET IN NOVEMBER

The August 1936 issue of Public Roads carried on page 127 a notice of the Sixteenth Annual Meeting of the Highway Research Board. The notice was incorrectly headed "Highway Research Board to meet in December." As stated in the text of the notice, this meeting will be held in Washington, D. C., November 18-20, 1936.

DISPOSITION OF STATE MOTOR-CARRIER TAX RECEIPTS, 1934

[Compiled from reports of State authorities]

State	Net total receipts of calendar year	Adjustments due to undistributed balances, etc.[1]	Net total funds distributed[2]	Expenses of collection and administration	For State highway purposes: Construction, maintenance, and administration[3]	State highway police[4]	Service of State highway obligations: State highway bonds	State-assumed local obligations[5]	Notes and other short-term loans	Total	Total for State highway purposes	For local roads[6]: For work on county and local roads	Service of local highway obligations	Total	For other highway purposes (park and forest roads, etc.)	For nonhighway purposes: To general funds[7]	For relief of unemployment or destitution	For education	For other purposes	Total
Alabama	$68,491	−$4,053	$64,438	$17,201	$32,189						$32,189	$15,048		$15,048						
Arizona	105,141	−2,198	102,943	10,520	88,683	$3,546					92,229								[8] $194	$194
Arkansas	19,495		19,495	606	7,007		$5,297	$3,493	$2,568	$11,358	18,365						$524			524
California	1,955,747	−79,122	1,876,625	448,855	302,844		800,000			800,000	1,102,844	302,844		302,844					[8] 22,082	22,082
Colorado	186,066	−536	185,530	6,381	102,669						102,669	73,847		73,847		$2,633				2,633
Connecticut	156,609	4,350	160,959		56,770						56,770					104,189				104,189
Delaware	(12)																			
Florida	178,221		178,221	36,745									$131,197	131,197		7,696		$2,583		10,279
Georgia	208,953	−2,537	206,416	129,238	77,178						77,178									
Idaho	40,617		40,617	19,871	20,044						20,044	702		702						
Illinois	(12)																			
Indiana	24,845	−19,277	5,568	5,568																
Iowa	382,637	−1,461	381,176	115,298								265,878		265,878						
Kansas	628,827	−2,836	625,991	191,041	223,037	63,309		32,305		32,305	318,651	116,299		116,299						
Kentucky	204,325	33,103	237,428	76,274	161,097	57					161,154									
Louisiana	856		856	856																
Maine	16,160	2,577	18,737	18,737																
Maryland	(13)																			
Massachusetts	51,411		51,411													51,411				51,411
Michigan	296,584	−58,563	238,021	171,378	66,643						66,643									
Minnesota	17,215		17,215	17,215																
Mississippi	73,309		73,309	1,353	542						542	71,214		71,214		200				200
Missouri	95,556	−20,738	74,818	74,818																
Montana	11,426	1,238	12,664	12,664																
Nebraska	[illegible]																			
Nevada	138,947	−170	138,777		134,127	4,650					138,777									
New Hampshire	4,452		4,452	4,452																
New Jersey	72,861		72,861		50,919						50,919	16,663	5,279	21,942						
New Mexico	67,299	10,929	78,228	12,350	52,245	13,633					65,878									
New York	[illegible]																			
North Carolina	204,154		204,154		69,301	966	78,887	4,013		82,900	153,167	42,268		42,268		8,719				8,719
North Dakota	15,281	2,153	17,434	14,896	2,538						2,538									
Ohio	360,219	123,898	484,117	95,680	214,835	9,283					224,118	164,319		164,319						
Oklahoma	610,043	−7,098	602,945	28,769	574,176						574,176									
Oregon	588,008	97,250	685,258	73,381	273,390	25,562	212,500			212,500	[illegible]	99,857		99,857	[illegible]					
Pennsylvania	1,977		1,977		1,211						1,211					766				766
Rhode Island	[illegible]																			
South Carolina	81,300	−15,102	66,198	15,264	47,082						47,082					3,852				3,852
South Dakota	264,073	21,985	286,058	27,409	247,849						247,849				10,800					
Tennessee	214,509	−20,324	194,185	52,335	79,088		6,446		5,662	12,108	91,196					[illegible]	[illegible]			[illegible]
Texas	52,115		52,115	48,465	3,650						3,650									
Utah	217,680	1,394	219,074	20,827	155,830	4,777					160,607					37,640				37,640
Vermont	[illegible]																			
Virginia	127,200	−12,396	114,804	17,328	71,065						71,065					26,411				26,411
Washington	186,227		186,227	186,227																
West Virginia	[illegible]																			
Wisconsin	1,063,468	14,644	1,078,112	456,411												[illegible]				[illegible]
Wyoming	58,000		58,000	[illegible]	[illegible]	1,108					[illegible]									
District of Columbia	112,313		112,313													[illegible]				[illegible]
Total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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[1] [illegible] and lags [illegible]

[2] [illegible] motor-f[illegible] ibution [illegible] ated [illegible]

[3] [illegible] streets

[4] [illegible] police [illegible] een pro[illegible]

[5] [illegible]

[6] [illegible]

[7] [illegible]

[8] [illegible]

DISPOSITION OF STATE MOTOR-

[Compiled from reports of State authorities]

State	Net total receipts of calendar year [1]	Adjustments due to undistributed balances, etc. [2]	Net total funds distributed [3]	Expenses of collection and administration	For other administrative purposes [4]	For State highway purposes						
						Construction, maintenance, and administration [5]	State highway police [6]	Service of State highway obligations				Total for State highway purposes
								State highway bonds	State-assumed local obligations [7]	Notes and other short-term loans	Total	
Alabama	$9, 225, 917	−$70	$9, 225, 847	$14, 003		$2, 180, 231	$24, 030	$2, 406, 968			$2, 406, 968	$4, 611, 229
Arizona	3, 024, 187		3, 024, 187	40, 369		1, 702, 770	68, 076					1, 770, 846
Arkansas	7, 776, 558	429, 484	8, 206, 042	269, 491		2, 529, 328		1, 911, 151	$1, 261, 393	$926, 775	4, 099, 319	6, 628, 647
California	36, 442, 897	62, 934	36, 379, 963	139, 112		24, 160, 567						24, 160, 567
Colorado	6, 445, 027	16, 811	6, 461, 838	83, 318		3, 151, 020						3, 151, 020
Connecticut	4, 849, 344	−144, 415	4, 704, 929	34, 014		4, 670, 915						4, 670, 915
Delaware	1, 187, 526		1, 187, 526	(14)		835, 037	82, 251	99, 133	171, 105		270, 238	1, 187, 526
Florida	16, 289, 940	6, 315	16, 296, 255	16, 645		6, 943, 560	38, 168		2, 322, 169		2, 322, 169	9, 303, 897
Georgia	14, 304, 590	−105	14, 304, 485	412, 842		9, 202, 722						9, 202, 722
Idaho	2, 853, 529	−23, 202	2, 830, 327	16, 628		2, 517, 209		214, 304			214, 304	2, 731, 513
Illinois	29, 214, 657	128, 210	29, 342, 867	148, 519		7, 950, 862						7, 950, 862
Indiana	17, 345, 642	30, 000	17, 375, 642	72, 642		8, 651, 500						8, 651, 500
Iowa	11, 027, 166	−39, 249	10, 987, 917	87, 830		2, 537, 242			3, 556, 845		3, 556, 845	6, 094, 087
Kansas	8, 546, 816	−43, 505	8, 503, 311	280, 746	$77, 553	4, 850, 122	63, 376		702, 503		702, 503	5, 616, 001
Kentucky	9, 055, 386	−3, 785	9, 051, 601	45, 057		9, 003, 333	3, 211					9, 006, 544
Louisiana	8, 909, 880	−526, 420	8, 383, 460	61, 000				6, 540, 484			6, 540, 484	6, 540, 484
Maine	4, 478, 037		4, 478, 037	11, 772		2, 758, 802	92, 788	1, 105, 835			1, 105, 835	3, 957, 425
Maryland	8, 291, 124		8, 291, 124	17, 300		2, 060, 078		1, 327, 722			1, 327, 722	3, 387, 800
Massachusetts	16, 951, 999		16, 951, 999	50, 000		3, 723, 746	171, 610	254, 733			254, 733	4, 150, 089
Michigan	20, 847, 905	58, 227	20, 906, 132	144, 757		9, 902, 072		4, 082, 060			4, 082, 060	13, 984, 132
Minnesota	10, 845, 376	−812, 747	10, 032, 629	(14)		6, 242, 404	138, 975					6, 381, 379
Mississippi	6, 859, 840	−1, 040	6, 858, 800	28, 834	90, 000	3, 604, 421	25, 192					3, 629, 613
Missouri	9, 681, 550	−8, 929	9, 672, 621	49, 180	98, 276	5, 108, 581	113, 736	4, 302, 848			4, 302, 848	9, 525, 165
Montana	3, 596, 007	−147, 804	3, 448, 203	20, 488		2, 384, 163		1, 043, 552			1, 043, 552	3, 427, 715
Nebraska	8, 587, 606		8, 587, 606	85, 760		5, 313, 653						5, 313, 653
Nevada	890, 589		890, 589	(21)		862, 071	1, 000		27, 518		27, 518	890, 589
New Hampshire	2, 795, 988		2, 795, 988	(22)		2, 069, 029		705, 392			705, 392	2, 774, 421
New Jersey	16, 787, 710	5, 376, 537	22, 164, 247	48, 355		7, 265, 174		7, 543, 463			7, 543, 463	14, 808, 637
New Mexico	2, 555, 614	191, 710	2, 747, 324	41, 220		1, 089, 295		1, 616, 809			1, 616, 809	2, 706, 104
New York [28]	43, 627, 570		43, 627, 570	90, 652		5, 152, 503		3, 627, 281			3, 627, 281	8, 779, 784
North Carolina	17, 050, 545		17, 050, 545	6, 094	21, 556	5, 546, 648	77, 342	6, 313, 892	321, 187		6, 635, 079	12, 259, 069
North Dakota	2, 218, 659	−3, 659	2, 215, 000	25, 000		1, 355, 988	2, 012			102, 000	102, 000	1, 460, 000
Ohio	37, 656, 775	−1, 578, 834	36, 077, 941	177, 017		15, 082, 308	254, 110					15, 336, 418
Oklahoma	10, 820, 684	382, 606	11, 203, 290	216, 414		5, 154, 528						5, 154, 528
Oregon	7, 215, 041	−26, 674	7, 188, 367	22, 400		3, 248, 815	196, 287	2, 525, 248			2, 525, 248	5, 970, 350
Pennsylvania	33, 356, 395	[30] −4, 786, 128	28, 570, 267	235, 391		21, 672, 868	702, 798	3, 088, 321			3, 088, 321	25, 463, 987
Rhode Island	2, 031, 526		2, 031, 526	(32)		1, 443, 728		301, 876			301, 876	1, 745, 604
South Carolina	7, 745, 565	−10, 579	7, 734, 986	(14)		747, 298		864, 372	4, 696, 837	135, 552	5, 696, 761	6, 444, 059
South Dakota	3, 784, 216	−84, 352	3, 699, 864	38, 255		1, 681, 277						1, 681, 277
Tennessee	14, 104, 099	−240, 960	13, 863, 139	142, 811		2, 704, 867		220, 444	1, 932, 685	2, 092, 143	4, 245, 272	6, 950, 139
Texas	31, 936, 718	−164, 444	31, 772, 274	224, 259		15, 774, 007			7, 887, 004		7, 887, 004	23, 661, 011
Utah	2, 489, 515	224, 699	2, 714, 214	(34)	14, 214	2, 619, 700	80, 300					2, 700, 000
Vermont	1, 942, 139	−237, 389	1, 704, 750	2, 000		415, 648		303, 816			303, 816	719, 464
Virginia	12, 496, 831	10, 666	12, 507, 497	164, 160	27, 325	6, 590, 047		264, 011			264, 011	6, 854, 058
Washington	11, 881, 753		11, 881, 753	19, 642		4, 850, 426						4, 850, 426
West Virginia	5, 612, 752		5, 612, 752	12, 663		2, 165, 984		2, 664, 352			2, 664, 352	4, 830, 336
Wisconsin	15, 345, 625	2, 599, 606	17, 945, 231	46, 080		8, 708, 953			2, 112, 075		2, 112, 075	10, 821, 028
Wyoming	1, 768, 243	−46, 246	1, 721, 997	7, 834		1, 159, 938	28, 372	112, 000			112, 000	1, 300, 310
District of Columbia	2, 132, 008	−206, 871	1, 925, 137	(14)								
Total	561, 885, 066	254, 530	565, 139, 596	3, 644, 554	328, 924	249, 345, 438	2, 163, 634	53, 440, 067	24, 991, 321	3, 256, 470	81, 687, 858	333, 196, 930

[1] Amounts tabulated in this column differ from totals given in a previous table issued by the Bureau State motor-fuel tax earnings, 1934, as actual collections rather than earnings of the calendar year are shown.

[2] In many States amounts distributed during the calendar year differ from actual collections because of undistributed balances carried over and lags between accounts of collecting and expending agencies. Proceeds of tax on gasoline used in aviation in Idaho, Michigan, Oregon, and Wyoming have been deducted as not being highway user taxes; also tax on nonhighway fuel in Ohio.

[3] In many States the proceeds of motor-fuel taxes, motor-vehicle fees, and motor-carrier taxes are placed in a common fund from which the distribution is made. In these cases the amounts distributed have been prorated in proportion to the receipts, not otherwise dedicated, from these three sources of revenue. See tables pp. 193, 196, and 197.

[4] Where reported separately from collection expenses, funds allotted for expenses of motor-fuel inspection, administration of motor vehicle department, and regulation of motor vehicles are shown in this column.

[5] Includes funds allotted for expenditure on urban extensions of State highway system, where reported separately from other funds allotted for local roads and streets.

[6] In cases where expenses of State highway police are paid out of State highway funds without specific allocations, expenditures for this purpose have been prorated in proportion to receipts not otherwise dedicated. See tables pp. 193, 196, and 197.

[7] County or local obligations assumed by State as reimbursement for local roads added to State system.

[8] In States indicated by star (*) the law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts so used were not reported separately.

[9] In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately.

[10] Except as noted, to State general funds for nonhighway purposes. Payments to county or municipal general funds may have been distributed in part for highways but amounts were not reported.

[11] Law in effect in 1934 provided that in counties of less than 18,000 population, 20 percent of the allotment could be used for schools. Amount so used not reported.

[12] For engineering expenses in connection with irrigation.

[13] Funds allotted to counties for use on both State and local roads.

[14] Paid out of general revenue. Amount not reported.

[15] For Dade Memorial Park, $365: Division of Airways, $8,842.

[16] For construction of prison camps.

[17] To ports of New Orleans and Lake Charles Harbor for harbor improvement

[18] To Conservation Department for oyster propagation, in consideration of fuel tax paid by motor workboats, $75,000; to Chesapeake Bay ferry companies, $35,040

FUEL TAX RECEIPTS, 1934

[Compiled from reports of State authorities]

For local roads and streets [8]					For nonhighway purposes					
For work on county and local roads	For work on city streets [9]	Service of local highway obligations	Total	For other highway purposes (park and forest roads, etc.)	To general funds	For relief of unemployment or destitution	For education	For other purposes	Total	State
[11] $4,600,615			$4,600,615							Alabama.
*906,932			906,932			$302,310		3,730	$306,040	Arizona.
966,476		$152,024	1,118,500			189,404			189,404	Arkansas.
*12,080,284			12,080,284							California.
[13] 1,508,500			1,508,500			1,719,000			1,719,000	Colorado.
										Connecticut.
										Delaware.
		4,644,337	4,644,337		$2,322,169			[15] 9,207	2,331,376	Florida.
2,301,013			2,301,013				$2,385,683	[16] 2,225	2,387,908	Georgia.
88,186			88,186							Idaho.
*6,173,917	*$6,954,228		13,128,145			1,810,880	6,304,461		8,115,341	Illinois.
6,921,200	1,730,300		8,651,500							Indiana.
*4,806,000			4,806,000							Iowa.
2,529,011			2,529,011							Kansas.
										Kentucky.
							890,988	[17] 890,988	1,781,976	Louisiana.
508,840			508,840							Maine.
1,377,151	2,397,517	988,356	4,763,024		12,960			[18] 110,040	123,000	Maryland.
2,237,374			2,237,374	$511,536	10,000,000				10,000,000	Massachusetts.
*6,772,993			6,772,993		4,250				4,250	Michigan.
*3,651,250			3,651,250							Minnesota.
*2,845,819			2,845,819					[19] 264,534	264,534	Mississippi.
										Missouri.
										Montana.
*2,870,491	317,702		3,188,193							Nebraska.
										Nevada.
		21,567	21,567							New Hampshire.
2,377,443		753,249	3,130,692			3,182,813	332,500	661,250	4,176,563	New Jersey.
										New Mexico.
*7,949,377			7,949,377		[27] 26,807,757				26,807,757	New York.
[28] 3,382,986			3,382,986		1,380,840				1,380,840	North Carolina.
730,000			730,000							North Dakota.
6,695,750	[29] 4,782,960		11,478,710				9,085,796		9,085,796	Ohio.
*2,651,067			2,651,067					[20] 3,181,281	3,181,281	Oklahoma.
*1,186,604			1,186,604	9,013						Oregon.
*2,472,490	254,498		2,726,988	70,481				73,420	73,420	Pennsylvania.
						285,922			285,922	Rhode Island.
*1,290,927			1,290,927							South Carolina.
				76,259				[33] 1,907,073	1,907,073	South Dakota.
3,988,939			3,988,939		268,343	318,990		[34] 2,193,917	2,781,250	Tennessee.
							7,887,004		7,887,004	Texas.
										Utah.
983,286			983,286							Vermont.
[36] 5,435,891			5,435,891			11,732		14,331	26,063	Virginia.
*6,063,628			6,063,628			948,057			948,057	Washington.
[28] 769,753			769,753							West Virginia.
3,378,440	500,421		3,878,861	36,295	[39] 3,162,967				3,162,967	Wisconsin.
413,853			413,853							Wyoming.
	1,925,137		1,925,137							District of Columbia.
112,916,486	18,862,763	6,559,533	138,338,782	703,584	43,959,286	8,769,108	26,886,432	9,311,996	88,926,822	Total

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[19] Paid out of general revenue, $173,981.

[20] For service of general State debt.

[21] Paid out of general revenue; estimated expense, $2,696.

[22] Included with expenses of motor vehicle department. See following table.

[23] Pro rata share of $44,638 paid for interest on highway relief bonds, a State obligation not issued for improvement of [illegible] roads.

[24] Return of loan made to sinking fund in 1933 from motor-fuel tax funds.

[25] For service of institution construction bonds, $326,475; reserve for service of unissued bonds, $244,775; to Department of Commerce and Navigation, $90,000.

[26] General fund appropriations for highway purposes have been credited against payments of motor fuel tax and motor-vehicle fees to the State general fund, and prorated in proportion to net receipts not otherwise dedicated. See following table. General fund appropriations for State police, $2,223,955, are not included, as amount assignable to highway traffic purposes was not reported

[27] Includes the following: Emergency 1-cent tax to State general fund, $14,542,523; net to State general fund after crediting expenses for highway purposes, $10,810,945; to general fund of New York City, $1,454,289.

[28] For county roads under State control.

[29] Under law effective in 1934 all or any portion of county and municipal allotments could be expended for work or poor relief. Amount so expended not reported. In cities situated on State highways one-sixth of municipal allotment to be used on urban extensions of State system.

[30] In addition to the change in undistributed balances this adjustment includes amount of loan from liquid-fuel tax fund to general funds for relief purposes, $1,650,000, and pro rata share of similar loan from motor license fund, $1,705,704. Law provides that these loans shall be repaid; they are therefore not included in the distribution.

[31] To Bureau of Aeronautics, $26,782; cooperative work other State departments, $46,638.

[32] Paid out of motor-vehicle fees, $15,315.

[33] To rural credit bond and interest fund.

[34] For service of general fund bonds, $1,994,470; service of Great Smoky Mountain Park bonds, $199,447.

[35] Appropriation for part of expenses of Division of Motor Vehicles, which collects the motor-fuel tax.

[36] For county roads under State control in all but three counties, $5,232,575; transferred to remaining three counties, $203,316.

[37] For aviation purposes.

[38] For service of $10,000,000 emergency relief bond issue, of which approximately $1,000,000 has been assigned to the State Highway Department for road work.

[39] Includes the following: To State general fund, $1,000,000; to towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles, $2,162,967.

DISPOSITION OF STATE MOTOR-

[Compiled from reports of State authorities]

State	Net total receipts of calendar year [1]	Adjustments due to undistributed balances [2]	Net total funds distributed [3]	Expenses of collection and administration [4]	For other administrative purposes [5]	For State highway purposes						
						Construction, maintenance, and administration [6]	State highway police [7]	Service of State highway obligations				Total for State highway purposes
								State highway bonds	State-assumed local obligations [8]	Notes and other short-term loans	Total	
Alabama	$3, 583, 689	$610	$3, 584, 299	$264, 033		$1, 014, 192		$1, 617, 075			$1, 617, 075	$2, 631, 267
Arizona	729, 246	-15, 743	713, 503	[illegible]		580, 178	$23, 195					603, 373
Arkansas	2, 233, 032		2, 233, 032	70, 612		802, 204		606, 142	$400, 065	$293, 937	1, 300, 144	2, 102, 348
California	9, 561, 100	-202, 086	9, 359, 014	1, 798, 349	36, 000	2, 743, 646	2, 088, 920					4, 832, 566
Colorado	2, 148, 657		2, 148, 657	243, 235	33, 888							
Connecticut	7, 947, 601	-482, 562	7, 465, 039	748, 397		3, 590, 663						3, 590, 663
Delaware	966, 612		966, 612	[illegible]		679, 695	66, 950	80, 692	139, 275		219, 967	966, 612
Florida	1, 485, 768	-12, 857	1, 472, 911	314, 907	152, 616							
Georgia	1, 192, 854	5, 136	1, 197, 990	118, 360	38, 324	1, 011, 061						1, 011, 061
Idaho	1, 561, 216	2, 832	1, 564, 048	77, 876		146, 211						146, 211
Illinois	18, 284, 195	847, 005	19, 131, 200	1, 158, 468		5, 903, 274	846, 754	8, 231, 100	441, 015		8, 672, 115	15, 422, 143
Indiana	7, 260, 187	29, 850	7, 290, 037	758, 011		2, 941, 535	206, 624					3, 148, 159
Iowa	9, 475, 978	−165, 090	9, 310, 888	645, 340		3, 607, 857			5, 057, 691		5, 057, 691	8, 665, 548
Kansas	3, 277, 935	13, 569	3, 291, 504	216, 801		1, 830, 897	23, 924		265, 192		265, 192	2, 120, 013
Kentucky	3, 122, 115	-13, 100	3, 109, 015	374, 169		2, 321, 681	7, 818					2, 329, 499
Louisiana	4, 379, 926	−43, 430	4, 336, 496	137, 458		3, 419, 772	291, 416	312, 850			312, 850	4, 024, 038
Maine	3, 098, [illegible]		3, 098, [illegible]	89, 653	12, 231	1, 849, 687	62, 212	741, 426			741, 426	2, 653, 325
Maryland	3, 856, 497	331, 665	4, 188, 162	370, 772	34, 077	2, 099, 404	210, 138	635, 566			635, 566	2, 945, 108
Massachusetts	7, 070, 766		7, 070, 766	1, 362, 468	35, 000	3, 060, 842	141, 060	209, 385			209, 385	3, 411, 287
Michigan	15, 901, 018	-188, 394	15, 712, 624	1, 053, 714		100, 000	200, 000					300, 000
Minnesota	6, 866, 573	14, 452	6, 881, 025	484, 732	360, 000	2, 145, 855	47, 773	2, 162, 000	1, 626, 425		3, 788, 425	5, 982, 053
Mississippi	1, 950, 393	811	1, 951, 204	96, 415		170, 383	1, 232					171, 615
Missouri	7, 374, 482		7, 374, 482	469, 653		3, 703, 230	82, 447	3, 119, 152			3, 119, 152	6, 904, 829
Montana	1, 070, 797		1, 070, 797	134, 693								
Nebraska	1, 895, 889	16, 107	1, 911, 996	78, 819		559, 629						559, 629
Nevada	248, 387	−1, 559	246, 828	17, 975		81, 461	25, 455	121, 937			121, 937	228, 853
New Hampshire	2, 469, 950		2, 469, 950	[17] 104, 570		2, 213, 372	121, 135	7, 802			7, 802	2, 342, 309
New Jersey	15, 975, 593		15, 975, 593	1, 111, 174		8, 731, 053						8, 731, 053
New Mexico	843, 382	4, 176	847, 558	103, 831		335, 751						335, 751
New York [20]	41, 628, 954		41, 628, 954	2, 266, 412		6, 929, 967		4, 878, 588			4, 878, 588	11, 808, 555
North Carolina	7, 114, 174		7, 114, 174	244, 884		2, 331, 804	32, 514	2, 654, 351	135, 026		2, 789, 377	5, 153, 695
North Dakota	1, 299, 126	−15, 103	1, 284, 023	84, 023		100, 000						100, 000
Ohio	20, 273, 129	32, 458	20, 305, 587	941, 575		3, 540, 030	152, 974					3, 693, 004
Oklahoma	3, 524, 084	56, 748	3, 580, 832	641, 805		1, 209, 660						1, 209, 660
Oregon	2, 248, 715	−79, 482	2, 169, 233	275, 741		858, 447	51, 866	667, 256			667, 256	1, 577, 569
Pennsylvania	32, 795, 312	[20] -1, 934, 296	30, 861, 016	1, 532, 656		24, 577, 379	796, 985	3, 502, 205			3, 502, 205	28, 876, 569
Rhode Island	2, 279, 178		2, 279, 178	261, 996	15, 315	1, 590, 079						1, 590, 079
South Carolina	2, 138, 480		2, 138, 480	175, 644		207, 881	170, 248	240, 448	1, 306, 552	37, 707	1, 584, 707	1, 962, 836
South Dakota	1, 313, 813	3, 179	1, 316, 992	45, 387		251, 100						251, 100
Tennessee	3, 440, 904	−15, 070	3, 425, 834	181, 710		2, 255, 986	181, 418	183, 860		132, 996	316, 856	2, 754, 260
Texas	14, 719, 736	1, 271	14, 721, 007	857, 105		4, 373, 572	231, 323					4, 604, 895
Utah	965, 601	-192, 329	773, 272	98, 272		145, 539	4, 461	525, 000			525, 000	675, 000
Vermont	2, 157, 314	14, 366	2, 171, 680	108, 000		503, 751		368, 215			368, 215	871, 966
Virginia	4, 948, 613	172, 965	5, 121, 578	323, 105		4, 421, 278	182, 858	186, 069			186, 069	4, 790, 205
Washington	3, 065, 882		3, 065, 882	304, 473	137, 537	2, 371, 183	179, 839					2, 551, 022
West Virginia	5, 623, 924		5, 623, 924	48, 024		2, 147, 838	22, 725	2, 642, 032			2, 642, 032	4, 812, 595
Wisconsin	10, 050, 779	1, 658, 863	11, 709, 642	642, 275	35, 000	5, 681, 393			1, 379, 389		1, 379, 389	7, 060, 782
Wyoming	448, 642		448, 642	10, 000		266, 133	6, 509	166, 000			166, 000	438, 642
District of Columbia	605, 309		605, 309	83, 903	13, 455							
Total	309, 141, 800	185, 038	309, 326, 838	21, 700, 364	903, 443	119, 406, 553	6. 460, 773	33, 859, 151	10, 750, 630	464, 640	45, 074, 421	170, 941, 747

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[1] Amounts given in this column differ in many cases from the totals of a previous table issued by the Bureau—State motor-vehicle receipts, 1934, which gives the receipts of the 1934 registration period.

[2] In many States amounts distributed during the calendar year differ from actual collections because of undistributed balances carried over and lags between accounts of collecting and expending agencies.

[3] In many States the proceeds of motor-fuel taxes, motor-vehicle fees, and motor-carrier taxes are placed in a common fund from which the distribution is made. In these cases the amounts distributed have been prorated in proportion to the receipts, not otherwise dedicated, from these three sources of revenue. See preceding tables.

[4] Collection expenses in many States include service charges deducted by county and local collectors. The amounts of such charges were estimated for Alabama, Florida, Kentucky, Ohio, Oklahoma, Tennessee, and Washington.

[5] Where reported separately from regular collection and administrative expenses of motor vehicle departments, funds allotted for collection of the motor-fuel tax, payments to auto theft fund, and miscellaneous expenses of motor-vehicle regulation are shown in this column.

[6] Includes funds allotted for expenditure on urban extensions of State highway system, where reported separately from other funds allotted for local roads and streets.

[7] In cases where expenses of State highway police are paid out of State highway funds without specific allocations, expenditures for this purpose have been prorated in proportion to receipts not otherwise dedicated. See preceding tables.

[8] County or local obligations assumed by State as reimbursement for local roads added to State system.

[9] In States indicated by star (*) the law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts so used were not reported separately.

[10] In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately.

[11] Except as noted, to State general funds for nonhighway purposes. Payments to county or municipal general funds may have been distributed in part for highways, but amounts were not reported.

[12] To county and municipal general funds.

[13] [illegible]

VEHICLE RECEIPTS, 1934

[Compiled from reports of State authorities]

For local roads and streets[9]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes					State
For work on county and local roads	For work on city streets[10]	Service of local highway obligations	Total		To general fund[11]	For relief of unemployment or destitution	For education	For other purposes	Total	
					[12] $688,999				688,999	Alabama.
								$1,271	1,271	Arizona.
						$60,072			60,072	Arkansas.
*$2,722,099			$2,722,099							California.
[14] 797,936			797,936		798,541	275,057			1,073,598	Colorado.
3,125,979			3,125,979							Connecticut.
										Delaware.
							$3,985,388		3,985,388	Florida.
								[16] 245	245	Georgia.
*1,339,961			1,339,961							Idaho.
2,107,751			2,107,751		142,838				142,838	Illinois.
1,176,614	$294,154		1,470,768		1,913,099				1,913,099	Indiana.
										Iowa.
954,690			954,690							Kansas.
405,347			405,347							Kentucky.
	175,000		175,000							Louisiana.
341,160			341,160							Maine.
14,979	823,226		838,205							Maryland.
1,839,074			1,839,074	$422,937						Massachusetts.
*13,979,417			13,979,417		379,493				379,493	Michigan.
					54,240				54,240	Minnesota.
*1,683,144			1,683,144							Mississippi.
										Missouri.
913,853	22,251		936,104							Montana.
1,273,548			1,273,548							Nebraska.
										Nevada.
		$23,071	23,071							New Hampshire.
5,167,136		905,230	6,072,366	61,000						New Jersey.
111,266			111,266		[19] 296,710				296,710	New Mexico.
*8,936,166			8,936,166		[21] 18,617,821				18,617,821	New York[20].
[22] 1,422,203			1,422,203		293,392				293,392	North Carolina.
								[23] 1,100,000	1,100,000	North Dakota.
*[24] 11,257,904	4,074,984		15,332,888					[25] 338,120	338,120	Ohio.
*1,729,367			1,729,367							Oklahoma.
*313,541			313,541	2,382						Oregon.
	288,605		288,605	79,927				[27] 83,259	83,259	Pennsylvania.
						411,788			411,788	Rhode Island.
										South Carolina.
1,009,564			1,009,564	10,941						South Dakota.
					223,811	266,053			489,864	Tennessee.
*9,259,007			9,259,007							Texas.
										Utah.
1,191,714			1,191,714							Vermont.
						8,268			8,268	Virginia.
72,850			72,850							Washington.
[22] 763,305			763,305							West Virginia.
2,226,513	308,744		2,535,257	23,705	[28] 1,412,623				1,412,623	Wisconsin.
										Wyoming.
					[29] 477,951				477,951	District of Columbia.
76,136,088	5,986,964	928,301	83,051,353	600,892	25,599,518	1,021,238	3,985,388	1,522,895	32,129,039	Total.

[14] Funds allotted to counties for use on both State and local roads.

[15] Paid out of general revenue.

[16] For construction of prison camps.

[17] Includes expenses of motor-fuel tax collection.

[18] To Commission for Elimination of Toll Bridges.

[19] To State general fund, $111,266; to county general funds, $185,444.

[20] General fund appropriations for highway purposes have been credited against payment of motor-fuel tax and motor-vehicle fees to the [illegible] in proportion to net receipts not otherwise dedicated. See preceding table. General fund appropriations for State police, $2,223,955, are not included, as amount assignable to highway traffic purposes was not reported.

[21] Includes the following: Net to State general fund after crediting appropriations for highway purposes, $14,540,408; to New York City general fund, $4,077,413.

[22] For county roads under State control.

[23] To real estate bond and interest fund.

[24] General law provides that this allotment shall be used for highway purposes. It is provided, however, that during 1933, 1934, and 1935 amounts shall be paid to counties and townships, for other than highway purposes, equal to amounts which would have been produced by the 1930 levies on personal property for other than highway purposes. Amounts so diverted were not reported.

[25] For hospitalization of indigent persons injured in motor-vehicle accidents.

[26] Pro rata share of temporary loan from motor-license fund to general fund for relief purposes. Law provides that loan shall be repaid. It is, therefore, not included in the distribution.

[27] To Bureau of Aeronautics, $30,372; cooperative work other departments, $52,887.

[28] To towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles.

[29] To District of Columbia general fund, United States Treasury.

DISPOSITION OF RECEIPTS FROM STATE

[Compiled from reports of State authorities]

	Net total receipts of calendar year	Adjustments due to undistributed balances, etc.[2]	Net total funds distributed	Expenses of collection and administration [3]	For State highway purposes						
					Construction, maintenance, and administration [4]	State highway police	Service of State highway obligations				Total for State highway purposes
							State highway bonds	State-assumed local obligations [5]	Notes and other short-term loans	Total	
Alabama	$12,878,097	−$3,513	$12,874,584	$295,237	$3,226,612	$24,030	$4,024,043			$4,024,043	$7,274,685
Arizona	3,888,574	−17,941	3,870,633	189,748	2,371,631	94,817					2,466,448
Arkansas	10,029,085	429,484	10,458,569	340,709	3,338,539		2,522,588	$1,664,953	$1,223,280	5,410,821	8,749,360
California	47,959,744	−344,142	47,615,602	2,392,316	27,207,057	2,088,920	800,000			800,000	30,095,977
Colorado	8,779,750	16,275	8,796,025	366,822	3,253,689						3,253,689
Connecticut	12,953,554	−622,627	12,330,927	782,411	8,318,348						8,318,348
Delaware	2,154,138		2,154,138	([15])	1,514,732	149,201	179,825	310,380		490,205	2,154,138
Florida	20,933,929	−6,542	20,927,387	520,913	6,943,560	38,168		2,322,169		2,322,169	9,303,897
Georgia	15,706,397	2,494	15,708,891	728,764	10,290,961						10,290,961
Idaho	4,455,362	−20,370	4,434,992	108,375	2,683,464		214,304			214,304	2,897,768
Illinois	47,498,852	975,215	48,474,067	1,306,987	13,854,136	846,754	8,231,100	441,015		8,672,115	23,373,005
Indiana	24,630,674	40,573	24,671,247	836,221	11,593,035	206,624					11,799,659
Iowa	20,885,781	−205,800	20,679,981	848,468	6,145,099			8,614,536		8,614,536	14,759,635
Kansas	12,453,578	−32,772	12,420,806	766,141	6,904,056	150,609		1,000,000		1,000,000	8,054,665
Kentucky	12,411,826	−13,782	12,398,044	495,500	11,486,111	11,086					11,497,197
Louisiana	13,290,662	−569,850	12,720,812	199,314	3,419,772	291,416	6,853,334			6,853,334	10,564,522
Maine	7,590,566	2,577	7,593,143	132,393	4,608,489	155,000	1,847,261			1,847,261	6,610,750
Maryland	12,147,621	331,665	12,479,286	422,149	4,159,482	210,138	1,963,288			1,963,288	6,332,908
Massachusetts	24,074,176		24,074,176	1,447,468	6,784,588	312,670	464,118			464,118	7,561,376
Michigan	37,045,507	-188,730	36,856,777	1,369,849	10,068,715	200,000	4,082,060			4,082,060	14,350,775
Minnesota	17,729,164	-798,295	16,930,869	861,947	8,388,259	186,748	2,162,000	1,626,425		3,788,425	12,363,432
Mississippi	8,883,542	−229	8,883,313	216,632	3,775,146	26,424					3,801,570
Missouri	17,381,588	-279,667	17,101,921	671,927	8,811,811	196,183	7,422,000			7,422,000	16,429,994
Montana	4,678,230	-146,566	4,531,664	167,845	2,384,163		1,043,552			1,043,552	3,427,715
Nebraska	10,483,495	16,107	10,499,602	164,579	5,873,282						5,873,282
Nevada	1,277,923	−1,729	1,276,194	17,975	1,077,659	31,105	121,937	27,518		149,455	1,258,219
New Hampshire	5,270,390		5,270,390	109,022	4,282,401	121,135	713,194			713,194	5,116,730
New Jersey	32,836,164	[13] 5,376,537	38,212,701	1,159,529	16,047,146		7,543,463			7,543,463	23,590,609
New Mexico	3,466,295	206,815	3,673,110	157,401	1,477,291	13,633	1,616,809			1,616,809	3,107,733
New York	85,256,524		85,256,524	2,357,064	12,082,470		8,505,869			8,505,869	20,588,339
North Carolina	24,368,873		24,368,873	272,534	7,947,753	110,822	9,047,130	460,226		9,507,356	17,565,931
North Dakota	3,533,066	−16,609	3,516,457	123,919	1,458,526	2,012			102,000	102,000	1,562,538
Ohio	58,290,123	-1,422,478	56,867,645	1,214,272	18,837,173	416,367					19,253,540
Oklahoma	14,954,811	432,256	15,387,067	886,988	6,938,364						6,938,364
Oregon	10,051,764	−8,906	10,042,858	371,522	4,380,658	273,515	3,405,010			3,405,010	8,059,183
Pennsylvania	66,153,684	-6,720,424	59,433,260	1,768,047	46,251,458	1,499,783	6,590,526			6,590,526	54,341,767
Rhode Island	4,310,704		4,310,704	277,311	3,033,807		301.876			301,876	3,335,683
South Carolina	9,965,345	−25,681	9,939,664	188,908	1,002,261	170,248	1,104,820	6,003,389	173,259	7,281,468	8,453,977
South Dakota	5,362,102	−59,188	5,302,914	111,051	2,180,226						2,180,226
Tennessee	17,759,512	−276,354	17,483,158	376,856	5,039,941	181,418	410,750	1,932,685	2,229,801	4,573,236	9,794,595
Texas	46,708,569	−163,173	46,545,396	1,129,829	20,151,229	231,323		7,887,004		7,887,004	28,269,556
Utah	3,672,796	33,764	3,706,560	133,313	2,921,069	89,538	525,000			525,000	3,535,607
Vermont	4,099,453	−223,023	3,876,430	110,000	919,399		672,031			672,031	1,591,430
Virginia	17,570,644	173,235	17,743,879	531,918	11,085,390	182,858	450,080			450,080	11,718,328
Washington	15,133,862		15,133,862	647,879	7,221,609	179,839					7,401,448
West Virginia	11,236,676		11,236,676	60,687	4,313,822	22,725	5,306,384			5,306,384	9,642,931
Wisconsin	26,430,872	4,302,513	30,733,385	1,179,766	14,390,346			3,491,464		3,491,464	17,881,810
Wyoming	2,274,885	−46,246	2,228,639	29,434	1,471,363	35,989	278,000			278,000	1,785,352
District of Columbia	2,889,630	−206,871	2,682,759	127,358							
Total	883,798,559	−81,998	883,716,561	28,975,298	371,916,098	8,751,098	88,402,352	35,781,764	3,728,340	127,912,456	508,579,652

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[1] Amounts listed include receipts from (1) motor-fuel taxes, (2) motor-vehicle fees and fines, and (3) special imposts on motor vehicles operated for hire (motor-carrier taxes). See preceding tables, which give distribution of these three classes of receipts separately.

[2] In many States amounts distributed during the calendar year differ from actual collections because of undistributed balances carried over and lags between accounts of collecting and expending agencies. Adjustments also include deduction of receipts not classed as highway user imposts, as follows: Proceeds of tax on gasoline used in aviation in Idaho, Michigan, Oregon, and Wyoming, and proceeds of tax on non-motor-vehicle fuel in Ohio.

[3] Includes expenses of collection and administration of motor-fuel tax, motor-vehicle fees, and motor-carrier taxes, and miscellaneous expenses of motor-vehicle regulation.

[4] Includes funds allotted for expenditure on urban extensions of State highway system, where reported separately from other funds allotted for local roads and streets.

[5] County or local obligations assumed as reimbursement for local roads added to State system.

[6] In States indicated by star (*) the law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts so used were not reported separately.

[7] In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately.

[8] Except as noted, to State general funds for nonhighway purposes Payments to county and municipal general funds may have been distributed in part for highways, but amounts were not reported.

[9] Law provided that part of county allotments could be used for schools. Amount not reported separately.

[10] To county and municipal general funds.

[11] For engineering expenses in connection with irrigation.

[12] To cities and counties for service of bonded debt.

[13] Funds allotted to counties for use on both State and local roads.

[14] To cities and towns.

[15] Paid out of general revenue.

[16] Includes $7,696 to cities and towns.

[17] For Dade Memorial Park, $365; Division of Airways, $8,842.

[18] For construction of prison camps.

[19] To ports of New Orleans and Lake Charles harbor for harbor improvement.

IMPOSTS ON HIGHWAY USERS, 1934

Compiled from reports of State authorities

For local roads and streets[9]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes					State
For work on county and local roads	For work on city streets	Service of local highway obligations	Total		To general fund	For relief of unemployment or destitution	For education	For other purposes	Total	
[9] $4,615,663			$4,615,663		[10] $688,999				$688,999	Alabama.
*906,932			906,932			$302,510		[11] 4,995	307,505	Arizona.
966,476		$152,024	1,118,500			250,000			250,000	Arkansas.
*15,105,227			15,105,227					[12] 22,082	22,082	California.
[13] 2,380,283			2,380,283		801,174	1,994,057			2,795,231	Colorado.
3,125,979			3,125,979		[14] 104,189				104,189	Connecticut.
										Delaware.
		4,775,534	4,775,534		[16] 2,329,865		$3,987,971	[17] 9,207	6,327,043	Florida
2,301,013			2,301,013				2,385,683	[18] 2,470	2,388,153	Georgia.
*1,428,849			1,428,849							Idaho.
*8,281,668	*$6,954,228		15,235,896		442,838	1,810,880	6,304,461		8,558,179	Illinois.
8,097,814	2,024,454		10,122,268		1,913,099				1,913,099	Indiana.
*5,071,878			5,071,878							Iowa.
3,600,000			3,600,000							Kansas.
405,347			405,347							Kentucky.
	175,000		175,000				890,988	[19] 890,988	1,781,976	Louisiana.
850,000			850,000							Maine.
1,392,130	3,220,743	988,356	5,601,229		12,960			[20] 110,040	123,000	Maryland.
4,076,448			4,076,448	$937,473	10,051,411				10,051,411	Massachusetts.
*20,752,410			20,752,410		383,743				383,743	Michigan.
*3,651,250			3,651,250		54,240				54,240	Minnesota.
*4,600,377			4,600,377		300			[21] 264,534	264,834	Mississippi.
										Missouri.
913,853	22,251		936,104							Montana.
*4,144,039	317,702		4,461,741							Nebraska.
										Nevada.
		[23] 44,638	44,638							New Hampshire.
7,561,242		[22] 1,663,758	9,225,000	[24] 61,000		3,182,813	332,500	[25] 661,250	4,176,563	New Jersey.
111,266			111,266		[26] 296,710				296,710	New Mexico.
*16,885,543			16,885,543		[28] 45,425,578				45,425,578	New York [27]
[29] 4,847,457			4,847,457		1,682,951				1,682,951	North Carolina.
730,000			730,000					1,100,000	1,100,000	North Dakota.
[31] *18,117,973	[31] *8,857,944		26,975,917				9,085,796	[32] 338,120	9,423,916	Ohio
*4,380,434			4,380,434					[21] 3,181,281	3,181,281	Oklahoma.
*1,600,000			1,600,000	12,153						Oregon.
*2,472,490	543,103		3,015,593	150,408	766			[34] 156,679	157,445	Pennsylvania.
						697,710			697,710	Rhode Island.
*1,290,927			1,290,927		5,852				5,852	South Carolina.
1,009,564			1,009,564	95,000				[30] 1,907,073	1,907,073	South Dakota.
3,988,939			3,988,939		534,481	594,370		[35] 2,193,917	3,322,768	Tennessee.
*9,259,007			9,259,007				7,887,004		7,887,004	Texas.
					37,640				37,640	Utah
2,175,000			2,175,000							Vermont.
[36] 5,435,891			5,435,891		23,411	20,000		[37] 14,331	57,742	Virginia.
*6,136,478			6,136,478			[38] 948,057			948,057	Washington.
[29] 1,533,058			1,533,058							West Virginia.
5,604,953	809,165		6,414,118	60,000	[39] 5,197,691				5,197,691	Wisconsin.
413,853			413,853							Wyoming.
	1,925,137		1,925,137		[40] 630,264				630,264	District of Columbia.
190,221,711	24,849,727	7,624,310	222,695,748	1,316,034	70,618,062	9,800,197	30,874,403	10,857,167	122,149,829	Total

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[20] To Conservation Department for oyster propagation, in consideration of fuel tax paid by motor workboats, $75,000; to Chesapeake Bay ferry companies, $35,040.

[21] For service of general State debt.

[22] Interest on highway relief bonds, a State obligation issued for improvement of local roads.

[23] Return of loan made to sinking fund in 1933 from motor-fuel tax funds.

[24] To Commission for Elimination of Toll Bridges.

[25] Service of institution construction bonds, $326,475; reserve for service of unissued bonds, $244,775; to Department of Commerce and Navigation, $90,000.

[26] To State general fund, $111,266; to county general funds, $185,444.

[27] General fund appropriations for highway purposes have been credited against payments of motor fuel tax and motor-vehicle fees to State general fund. General fund appropriations for State police, $2,223,955, are not included, as amount assignable to highway traffic purposes was not reported.

[28] Net to State general fund after crediting appropriations for highway purposes, $39,893,876; to New York City general fund, $5,531,702.

[29] For county roads under State control.

[30] For payments on real estate bonds.

[31] Law provided for diversion of county and municipal allotments for relief and general fund purposes. Amounts so used not reported separately.

[32] For hospitalization of indigent persons injured in motor-vehicle accidents.

[33] Undistributed balance adjustment, $1,430,424; temporary loans to State general fund for relief purposes, $5,290,000.

[34] To Bureau of Aeronautics, $57,154; cooperative work for other State departments, $99,525.

[35] Service of general fund bonds, $1,994,470; service of Great Smoky Mountain Park bonds, $199,447.

[36] For county roads under State control in all but three counties, $5,232,575; transferred to remaining three counties, $203,316.

[37] For aviation purposes.

[38] For service of $10,000,000 emergency relief bond issue, of which approximately $1,000,000 has been assigned to the State highway department for road work.

[39] To State general fund, $1,622,101; to towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles, $3,575,590.

[40] To District of Columbia general fund, United States Treasury.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936-1937

AS OF SEPTEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287				$ 600,792	$ 300,396	23.2				$ 4,907,891
Arizona	3,564,709	$ 1,715,491	$ 1,342,097	97.9	693,818	569,235	18.9	$ 51,278	$ 36,469	0.5	1,616,908
Arkansas	4,275,929										4,275,929
California	9,508,671	2,550,716	1,461,159	63.9	7,942,378	4,562,251	207.4	3,404,308	1,962,007	96.3	1,523,254
Colorado	4,575,144	1,840,007	1,029,883	81.7	2,804,422	1,556,429	90.9	1,057,477	540,227	30.8	1,448,604
Connecticut	1,582,913	98,677	49,339	2.3	1,002,078	498,836	12.7	122,827	61,414	1.3	973,324
Deleware	1,218,750	239,537	119,769	30.3	314,121	157,061	9.8	297,184	143,247	9.2	798,674
Florida	3,315,558	674,678	337,339	23.8	418,048	209,024	12.5	373,758	186,879	10.5	2,582,316
Georgia	6,336,443	464,012	225,780	38.6	2,627,784	1,289,573	160.2	641,905	320,937	33.8	4,500,152
Idaho	3,065,304	1,034,361	613,014	141.3	2,128,079	1,273,647	141.8	376,210	225,123	32.7	953,520
Illinois	10,325,922	2,331,366	1,162,842	49.0	7,813,359	3,872,205	116.2	3,461,729	1,705,439	87.6	3,585,436
Indiana	6,184,258	2,848,317	1,422,739	95.9	3,346,325	1,673,054	111.7	4,134,654	2,066,528	103.2	1,021,936
Iowa	6,466,628	4,641,682	2,191,504	353.7	3,443,716	1,650,619	144.0	2,553,600	1,234,688	90.8	1,389,817
Kansas	6,631,085	1,793,775	896,253	379.5	4,491,006	2,219,056	462.7	2,583,651	1,291,775	191.4	2,224,001
Kentucky	4,611,955	1,930,787	946,458	128.8	312,862	156,431	14.6	1,318,263	654,685	49.3	2,854,381
Louisiana	3,557,930	1,317,155	658,577	48.6	1,255,693	627,846	42.6	688,056	344,028	16.1	1,927,478
Maine	2,177,197	1,562,025	780,215	45.1	353,803	176,902	13.5	624,164	312,082	15.2	907,999
Maryland	2,050,870				801,807	400,891	11.3	937,600	428,277	12.5	1,221,702
Massachusetts	3,485,364				607,382	303,691	5.1	4,245,162	2,072,581	15.6	1,109,092
Michigan	7,668,768	2,734,635	1,365,820	119.6	10,526,518	5,260,534	311.3	1,494,150	747,075	42.8	295,339
Minnesota	6,849,307	5,258,491	2,432,883	343.5	3,932,447	1,895,380	215.3	884,937	437,069	59.1	2,083,975
Mississippi	4,387,636							1,278,527	639,264	79.1	3,748,372
Missouri	7,601,200	2,358,122	1,174,934	329.8	5,710,371	2,855,188	249.1	3,299,430	1,649,426	178.7	1,921,653
Montana	5,122,333	3,034,250	1,698,744	347.4	1,816,992	1,017,334	88.7	1,691,764	909,027	122.0	1,497,229
Nebraska	5,167,930	1,195,001	597,421	79.8	3,533,477	1,772,321	318.7	771,157	385,579	55.3	2,412,610
Nevada	3,189,479	977,671	841,760	161.5	1,083,200	936,706	121.6	5,280	4,571		1,406,442
New Hampshire	1,218,750	606,373	296,960	19.2	310,662	155,034	5.9	153,317	76,580	1.9	690,177
New Jersey	3,352,469	565,970	282,965	12.0	2,519,053	1,172,996	27.8	840,561	420,280	4.6	1,476,227
New Mexico	3,990,023	1,968,542	1,196,172	158.9	2,016,709	1,248,630	139.1	826,005	495,025	82.0	1,050,197
New York	12,306,710	1,678,650	834,050	39.0	14,336,629	7,084,297	245.4	3,809,700	1,856,850	82.6	2,531,513
North Carolina	5,879,466	1,211,240	605,535	172.5	3,200,278	1,598,744	338.5	523,188	234,912	19.8	3,440,275
North Dakota	3,918,269				191,740	101,206	.1				3,817,063
Ohio	9,131,204	371,310	185,655	7.7	6,335,933	3,086,583	84.1	1,805,832	843,768	11.3	5,015,198
Oklahoma	5,884,927	1,641,493	862,294	58.1	1,831,441	960,167	64.6	1,569,552	769,283	57.6	3,293,183
Oregon	4,089,711	1,352,422	824,129	66.4	2,761,661	1,622,346	80.1	1,536,789	922,400	54.6	720,836
Pennsylvania	10,695,448	2,340,909	1,170,186	43.8	8,427,006	4,206,467	112.9	4,399,879	2,187,950	62.7	3,130,846
Rhode Island	1,218,750				208,875	104,437	3.4	243,555	121,778	2.8	992,535
South Carolina	3,381,337				2,429,867	1,104,160	177.6	1,640,210	731,758	161.0	1,545,419
South Dakota	4,078,647	854,323	468,425	98.4	577,260	345,728	94.6				3,264,493
Tennessee	5,268,270	1,704,450	851,653	72.1	841,758	420,869	29.6	399,154	199,577	16.6	3,796,171
Texas	15,548,821	7,791,060	3,886,592	427.9	6,813,093	3,387,335	352.1	666,017	332,133	22.9	7,942,760
Utah	2,826,960	1,455,473	1,043,447	117.4	625,542	448,669	22.9	405,733	292,745	31.6	1,042,098
Vermont	1,218,750	1,095,920	546,796	57.0	494,946	235,377	11.2	402,351	182,121	11.3	254,456
Virginia	4,559,200	814,162	404,727	29.4	2,605,223	1,302,610	98.6	2,160,115	1,080,057	82.5	1,771,806
Washington	3,904,738	1,975,267	1,039,603	72.8	2,980,111	1,567,071	111.9	840,750	442,000	45.7	856,064
West Virginia	2,716,754	168,656	84,328	7.2	1,326,321	663,144	48.4	665,550	332,775	17.2	1,636,507
Wisconsin	6,090,504	1,935,732	958,207	71.7	5,167,168	2,464,292	191.6	1,114,173	549,104	44.6	2,118,901
Wyoming	3,121,972	2,466,893	1,503,780	274.6	1,221,858	741,659	204.5	223,190	136,535	16.6	739,998
District of Columbia											
Hawaii	1,218,750				467,855	231,167	8.2	69,938	34,754	1.6	952,829
TOTALS	243,750,000	72,599,601	38,394,034	4,768.1	135,251,467	69,487,598	5,356.9	60,592,630	30,600,782	2,165.3	105,267,586

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF SEPTEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Fund	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 101,939	$ 101,939	6.0	$ 3,810,847	$ 3,810,847	121.2	$ 78,320	$ 78,320	1.7	$ 160,008
Arizona	2,569,841	1,489,227	1,370,358	104.3	1,534,995	1,109,692	92.5				89,290
Arkansas	3,352,061	1,394,349	1,379,540	117.6	1,815,026	1,810,391	220.9	80,705	80,455	8.5	81,675
California	7,747,928	2,803,507	2,664,534	132.9	4,912,339	4,839,151	114.6	160,841	160,341	1.5	83,402
Colorado	3,395,263	1,235,463	1,234,656	71.9	839,734	839,734	26.2	60,717	60,717	6.0	1,260,155
Connecticut	1,418,709	16,288	15,385		464,599	443,314	3.7	245,716	245,716	2.4	713,894
Delaware	900,310	131,410	131,410	27.2	481,162	452,322	21.9	250,398	171,583	17.7	144,995
Florida	2,597,144	257,702	257,702	17.2	2,055,796	2,055,796	69.4	251,977	251,977	12.5	31,669
Georgia	4,988,967	321,413	320,725	14.7	607,557	607,557	48.8	518,414	518,414	27.2	3,542,171
Idaho	2,222,747	895,369	885,354	80.0	1,341,434	1,305,028	103.3				32,365
Illinois	8,594,009	2,911,003	2,910,672	174.9	5,409,679	5,409,679	276.0	345,252	345,252	16.6	28,406
Indiana	4,941,255	437,242	437,242	17.1	4,628,250	4,408,346	211.5	37,924	37,924	6.3	57,742
Iowa	4,391,564	1,469,869	1,398,300	240.0	3,378,116	3,291,084	229.1	376,771	296,326	43.9	4,955
Kansas	4,994,975	1,131,749	1,131,740	148.2	3,864,040	3,854,229	226.8	9,006	9,006	.2	
Kentucky	3,726,271	1,244,134	1,244,134	175.3	1,419,036	1,419,036	126.5	757,567	757,558	47.4	305,543
Louisiana	2,890,429	275,630	159,229	14.5	2,458,750	2,241,343	137.7	410,499	345,560	22.4	144,297
Maine	1,676,799	732,945	732,398	30.3	838,234	637,622	39.7	52,100	52,100	1.7	254,679
Maryland	1,750,738	60,038	60,038	3.0	331,130	370,516	13.6	1,021,267	868,441	25.0	451,643
Massachusetts	3,262,385				1,438,247	1,438,247	7.9	796,617	736,617	9.8	1,028,021
Michigan	6,301,414	3,260,700	3,260,700	154.4	2,872,721	2,312,691	129.9	55,700	55,700	4.6	172,323
Minnesota	5,277,145	2,963,108	2,572,500	547.0	2,627,986	2,215,522	323.9	867,609	474,973	41.2	14,150
Mississippi	3,457,552	719,422	718,452	62.9	2,305,857	2,302,431	136.9	162,219	162,219	16.1	274,450
Missouri	6,012,652	2,718,238	2,706,846	630.7	2,803,661	2,693,317	143.2	339,006	226,825	3.7	385,563
Montana	3,676,416	2,614,737	2,614,737	142.4	993,301	993,301	42.9				68,379
Nebraska	3,870,739	845,750	831,425	109.9	2,473,897	2,441,909	240.9	312,435	312,435	12.9	284,971
Nevada	2,243,074	1,470,400	1,430,585	64.6	473,737	467,194	24.0	77,629	77,629	2.6	267,667
New Hampshire	945,225	324,723	321,354	17.0	431,916	409,528	15.6				214,343
New Jersey	3,129,305	58,780	58,780	1.8	2,133,098	2,133,098	17.2	778,963	755,514	13.3	182,413
New Mexico	2,871,397	1,453,988	1,453,502	135.9	898,802	898,802	43.7	93,636	93,636	5.2	425,458
New York	11,046,377	2,705,568	2,676,182	44.7	8,392,705	8,008,329	123.2	359,309	351,959	2.5	9,906
North Carolina	4,726,173	551,112	551,112	27.1	3,386,648	3,354,047	238.7	695,295	602,423	21.7	212,591
North Dakota	2,867,245	374,763	374,601	72.3	2,034,980	2,030,451	201.4	259,893	259,893	35.3	202,300
Ohio	7,670,815	606,549	606,549	12.3	4,830,154	4,733,059	148.9	1,455,250	1,381,042	108.6	950,164
Oklahoma	4,580,670	692,033	690,423	66.6	2,415,714	2,413,098	227.5	927,489	927,489	87.5	549,661
Oregon	3,038,642	1,172,627	1,167,752	83.8	1,963,366	1,598,824	65.4	140,959	139,069	11.6	133,057
Pennsylvania	9,347,797	1,073,030	1,011,371	54.9	1,655,452	1,651,414	50.8	1,085,961	1,043,651	57.0	5,641,361
Rhode Island	985,208	476,165	468,554	9.5	510,981	510,981	9.3				9,673
South Carolina	2,762,012	469,591	456,514	51.3	1,671,161	1,605,655	151.5	196,306	191,852	19.8	447,991
South Dakota	2,976,454	1,087,296	1,087,296	240.9	1,283,251	1,283,251	179.7	317,440	317,440	41.9	288,467
Tennessee	4,132,460	905,360	905,360	36.1	1,810,211	1,810,211	74.5	562,465	562,465	24.7	854,424
Texas	11,989,350	[illegible]	7,076,306	717.9	5,254,549	4,753,964	391.3	117,411	101,511	8.7	57,269
Utah	2,067,154	1,007,085	962,757	118.1	894,005	778,821	62.8	185,682	185,609	7.6	139,968
Vermont	924,306	454,213	404,129	12.5	565,438	474,853	9.3	8,000	8,000		37,724
Virginia	3,652,667	1,653,573	1,599,960	622.0	1,449,486	1,429,711	362.6	410,719	410,719	55.0	212,277
Washington	3,026,161	[illegible]	1,738,958	123.7	1,314,585	1,123,219	33.9	146,120	146,120	2.1	17,864
West Virginia	2,231,412				1,677,312	1,673,772	69.8	446,251	444,511	20.4	113,129
Wisconsin	4,823,944	2,136,332	1,918,328	169.6	3,313,578	2,858,458	165.4	[illegible]	42,760	[illegible]	4,398
Wyoming	2,219,155	616,232	616,223	43.8	1,481,906	1,481,894	95.2	92,292	92,291	1.2	28,747
District of Columbia	944,496	966,869	944,339	8.5				25,011	[illegible]	.2	362
Hawaii	966,033	95,216	82,604	1.3	549,947	541,612	7.6	9,684	9,146		292,671
TOTALS	195,000,000	60,100,375	57,745,555	5,763.6	106,149,826	102,027,551	5,878.3	15,654,637	[illegible]	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF SEPTEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 192,848	$ 192,848	4		3	$ 3,159,717	$ 3,159,717	32		1	$ 541,813	$ 541,813	5		7	$ 140,239
Arizona	1,256,099	398,678	394,443	5			723,343	711,898	7								149,758
Arkansas	3,574,060	307,299	804,562	21	2		1,869,002	1,863,714	27	3		790,441	789,527	8		29	116,257
California	7,486,362	1,128,082	1,102,777	9	5		6,236,139	6,067,159	43	2							316,426
Colorado	2,631,567	926,063	905,063	17			639,929	639,929	6	1							1,086,575
Connecticut	1,712,684						73,479	73,479		1		578,069	505,990	3	1		1,133,215
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	376,085	376,085	3	2		1,544,580	1,542,270	16	3		471,191	471,191	11			438,337
Georgia	4,895,949	12,090	12,090	1			318,336	318,336	5	2		473,993	473,993	15			4,091,530
Idaho	1,674,479	608,364	608,364	10	1		508,469	508,469	7			32,026	32,026			18	525,620
Illinois	10,307,184	494,347	494,347	9			6,791,679	6,791,679	45	3		1,883,683	1,883,683	12	1		1,137,475
Indiana	5,111,096	123,346	123,346	3			4,747,743	4,624,624	34	11		413,314	89,585			161	273,541
Iowa	5,600,679	482,788	460,597	16	2		4,343,949	4,284,978	77	7		431,856	422,512	6	1	6	432,593
Kansas	5,246,258	510,952	510,952	7			4,661,942	4,606,514	45	1		128,792	128,792	3		3	
Kentucky	3,672,387	15,290	15,290	1			2,512,919	2,223,187	20			254,862	254,862	2	4		1,179,048
Louisiana	3,213,467						1,108,330	1,108,330	10	1		1,291,648	1,247,183	11	3		857,954
Maine	1,426,861	284,698	284,365	8			753,736	753,145	10			129,755	129,755	3		2	259,596
Maryland	2,061,751						477,688	469,649	4	2		1,061,147	1,038,679	4	2	18	553,423
Massachusetts	4,210,833	117,449	117,449	2			1,758,553	1,758,553	13	2		1,132,733	1,132,733	6	2		1,202,097
Michigan	6,765,197	1,122,725	1,122,725	14	3		5,026,327	4,981,827	28	4		400,100	400,100	1			260,545
Minnesota	5,395,441	808,291	808,291	32	1	19	3,305,846	3,299,750	47	8	21	614,462	614,462	4	1	1	672,938
Mississippi	3,241,475	25,677	25,677	2	1		2,230,582	2,230,582	45	2		323,769	323,769	5		1	661,447
Missouri	6,142,153	179,101	179,101	3			5,715,757	5,640,491	42			375,538	261,586	1		2	60,975
Montana	2,722,327	1,915,443	1,915,443	30	5		678,538	678,538	6	1		66,336	66,336	1			62,009
Nebraska	3,556,441	477,487	477,487	14			1,689,970	1,689,970	55	1	5	1,270,689	1,270,689	10	1	18	118,295
Nevada	887,260	306,096	306,096	7	2		599,335	577,534	4			3,630	3,630			5	
New Hampshire	822,484	151,745	151,745	1			350,493	350,493	4	2	1						320,246
New Jersey	3,983,826						1,492,673	1,492,673	9	2		1,097,620	1,097,620	8	1		1,393,534
New Mexico	1,725,286	370,259	370,259	8			1,079,279	1,079,279	8	1		72,213	72,213	1			203,534
New York	13,577,189	46,040	46,040		2		10,502,004	10,241,158	33	34		1,389,433	1,389,433	1	2		1,900,558
North Carolina	4,823,958	202,566	202,566	4	4		2,133,274	2,133,274	27	8		1,010,966	995,466	8	4	61	1,492,653
North Dakota	3,207,473	189,807	189,807	5			1,826,095	1,825,095	35	1		17,430	17,430	1			1,175,141
Ohio	8,439,897						2,982,291	2,834,726	20	2		2,628,393	2,542,404	15	3		3,062,767
Oklahoma	5,004,711	1,143,162	1,143,162	25	1		1,637,970	1,637,970	16	2		618,519	618,519	13	1		1,605,061
Oregon	2,334,204	192,665	192,665	2	2		2,192,229	2,067,518	14	4		74,021	74,021	1		2	
Pennsylvania	11,483,613	233,539	182,306	15			5,309,829	4,983,227	36	13		1,607,150	1,217,083	8	2		5,100,997
Rhode Island	699,691	236,879	236,879		1		418,195	417,129	4								45,683
South Carolina	3,059,956	255,347	252,043	8		[illegible]	1,432,872	1,424,890	20	7	1	334,714	334,584	8		49	1,048,439
South Dakota	3,249,086	356,492	356,492	14			1,291,117	1,291,117	29	1		540,610	540,610	11		30	1,060,866
Tennessee	3,903,979	139,050	139,050	5		3	567,566	567,566	9	2	1	1,396,578	1,396,578	16	1	17	1,800,785
Texas	10,855,982	1,550,651	1,550,651	29	4		6,935,498	6,929,123	82	10		2,062,227	2,009,265	13	1	164	366,943
Utah	1,230,763	31,146	29,757		1		762,088	754,041	11			324,648	308,000	2			138,965
Vermont	729,857	364,025	361,180	7	4		98,394	98,394		1		285,298	223,830	3	1	12	46,454
Virginia	3,774,287	316,040	316,040	13	1		1,679,882	1,570,018	27	2		694,339	694,335	15	3	12	4,193,894
Washington	3,095,041	434,369	429,569	7	3	2	2,416,857	2,416,432	15	8	3	4,290	4,290			2	244,750
West Virginia	2,677,937						618,942	618,942	6	1		716,838	716,838	14	1	4	1,342,157
Wisconsin	5,022,683	621,115	621,115	7			3,654,266	3,626,169	27	6		192,988	160,720	2			614,678
Wyoming	1,360,841	55,366	55,365	2			930,633	930,628	7			78,404	78,403	2			296,445
Dist. of Columbia	410,804						425,564	396,804	3								14;000
Hawaii	453,703						522,380	453,703	5								
TOTALS	196,000,000	18,203,462	18,064,089	370	47	29	112,929,765	110,864,691	1076	162	33	27,816,526	26,574,538	253	36	624	40,496,682

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Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF SEPTEMBER 30, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,253,242	$ 15,252,420	$ 8,290,736	$ 3,470,875	759.0	$ 499,761	$ 52,665	$ 447,096	17.0		$ 304,982	2.5	$ 26,732	$ 26,889
Arizona	5,211,960	2,641,935	8,982,676	5,204,513	2,570,966	543.0	12,500		12,500					7,447	58,469
Arkansas	6,748,335	3,428,049	10,908,286	6,634,440	3,304,963	618.5	87,816		87,606	1.5	$ 70,814	18,148	3.2	43,081	17,332
California	15,607,354	7,932,206	30,595,484	15,589,248	7,751,647	760.9	115,026		115,016			820		18,105	64,723
Colorado	6,874,530	3,486,006	11,209,862	6,831,431	3,441,857	639.8								43,099	44,149
Connecticut	2,865,740	1,454,868	4,443,623	2,756,269	1,255,341	73.1	107,242	36,318	57,603	1.0	22,245			48,909	141,924
Delaware	1,219,088	923,395	2,676,358	1,218,804	815,188	128.3	53,319		53,319	.5		52,205	1.1	284	2,682
Florida	5,231,834	2,661,343	8,735,667	5,175,534	2,193,358	299.6	389,401		358,854	9.3		15,955	.8	56,300	93,165
Georgia	10,091,185	5,113,491	12,676,939	9,187,568	2,774,071	718.1	1,633,523	541,346	1,074,148	107.6	64,072	125,508	3.3	278,199	1,139,764
Idaho	4,486,249	2,277,486	6,741,735	4,416,568	1,904,256	500.9	346,409		342,613	.5	42,905	1,521		26,776	29,096
Illinois	17,570,770	8,921,401	24,887,419	16,828,002	7,140,842	670.2	2,574,610	680,180	1,688,110	46.7	15,674	18,214	5.4	46,915	74,235
Indiana	10,037,343	5,088,963	15,194,693	9,775,380	4,725,577	464.6	441,723	206,489	205,932	23.8		108,068		55,974	49,386
Iowa	10,055,660	5,118,361	15,428,980	10,055,161	4,777,361	1,261.9	361,841		341,000	5.4	499				
Kansas	10,089,604	5,117,675	15,326,260	10,002,650	5,011,108	1,131.1	226,121	77,553	60,318	14.4				9,401	46,249
Kentucky	7,517,359	3,818,311	11,196,442	7,448,139	3,459,949	806.7	317,146	59,003	241,546	6.1		37,329	2.1	10,217	79,488
Louisiana	5,828,591	2,963,932	8,971,463	5,755,322	2,591,893	249.9	174,054	56,550	117,504	9.5		223,172	11.6	16,719	31,363
Maine	3,369,917	1,711,586	5,232,163	3,346,881	1,657,506	193.1	7,234		7,234					23,036	46,846
Maryland	3,564,527	1,810,058	5,113,898	3,235,963	856,905	136.8	673,286	240,565	398,299	21.2		312,399	3.4	87,999	242,455
Massachusetts	6,597,100	3,350,474	9,840,782	6,552,733	2,635,951	115.2	443,755		443,755	.3		91,944	.1	44,367	178,824
Michigan	12,736,227	6,452,568	20,176,587	12,696,114	5,879,433	745.1	535,775	40,113	435,198	23.1		136,788	.4		1,149
Minnesota	10,656,569	5,425,551	16,082,221	10,515,640	4,758,425	1,625.8	500,948	60,099	382,030	22.0		17,660	1.3	80,830	267,435
Mississippi	6,978,675	3,540,227	12,401,629	6,723,551	2,717,221	707.6	930,998	188,860	742,138	36.4	3,960	41,111	1.7	62,304	39,697
Missouri	12,180,306	6,173,740	17,405,575	11,637,146	4,721,768	1,436.3	2,108,797	471,210	1,375,607	15.3		67,385		71,950	8,980
Montana	7,439,748	3,769,734	11,649,966	7,405,326	3,571,311	1,045.4	204,864	18,440	186,424	13.0				15,982	11,999
Nebraska	7,828,961	3,964,364	12,800,048	7,775,584	3,614,698	1,018.3	275,979		263,874	27.8	38,017	69,961	5.9	15,360	15,832
Nevada	4,545,917	2,302,356	7,041,816	4,545,917	2,272,477	760.4	25,004		25,004			3,450			1,425
New Hampshire	1,909,839	969,462	2,971,426	1,904,950	933,904	77.7	4,174		4,174			16,591	.5	4,888	14,793
New Jersey	6,346,039	3,220,879	7,890,090	6,050,468	1,334,004	81.1	2,313,106	100,118	1,684,378	14.3	103,825		1.3	91,629	202,497
New Mexico	5,792,935	2,941,700	8,750,864	5,742,415	2,801,073	743.6	90,789	40,093	38,402	6.0				10,427	102,225
New York	22,330,101	11,327,921	38,610,905	21,810,435	9,904,437	814.7	1,870,220	351,500	1,149,599	8.7	140,263	205,575	1.7	27,903	68,309
North Carolina	9,522,293	4,840,941	14,534,457	9,055,926	4,304,060	1,329.6	621,910	390,134	231,776	27.7	63,117	200,873	8.2	13,115	104,232
North Dakota	5,804,448	2,938,967	8,165,538	5,607,892	1,831,376	2,080.5	584,173	55,232	512,440	56.6	97,879	100,382	16.6	43,445	494,770
Ohio	15,484,592	7,865,012	23,853,335	15,324,142	6,727,618	771.2	1,063,416	101,165	964,126	23.7		59,160	1.4	59,285	114,109
Oklahoma	9,216,798	4,685,180	14,454,246	9,146,852	4,237,720	804.4	239,170	67,007	172,163	1.8		7,995	.4	2,938	267,302
Oregon	6,106,896	3,097,614	9,785,647	5,989,401	2,911,569	465.4	221,469	64,950	89,127	3.3		25,041		52,545	72,078
Pennsylvania	18,891,004	9,590,788	28,223,264	18,181,618	8,667,568	1,020.4	939,331	432,418	415,018	38.0	3,288	212,482	1.7	273,080	295,721
Rhode Island	1,998,708	1,014,572	3,140,657	1,998,708	1,008,873	79.1						3,806			1,893
South Carolina	5,459,165	2,770,954	7,666,405	5,233,441	2,158,259	609.9	480,000	98,074	371,116	15.2	118,761	150,063	4.0	8,889	91,516
South Dakota	6,011,479	3,047,643	9,100,736	5,777,466	2,747,494	1,529.1	356,426	143,433	212,993	49.5		26,867	13.7	90,560	60,289
Tennessee	8,492,619	4,306,991	13,183,797	8,492,619	3,680,429	483.6	462,716		462,716	9.0		113,346	9.5		50,500
Texas	24,244,024	12,291,253	37,666,237	23,937,965	11,929,917	2,776.0	613,756	254,494	244,051	9.2		500	7.1	51,564	116,785
Utah	4,134,708	2,132,691	7,141,769	4,100,916	1,991,960	590.6	150,018		140,731	.3	32,292			1,500	
Vermont	1,867,573	948,007	3,045,526	1,863,531	840,471	137.9	121,734	3,922	102,184	3.1				121	5,352
Virginia	7,416,757	3,765,387	11,589,851	7,298,633	3,342,708	598.7	159,266	704	158,562	21.8	86,473	176,315	28.9	30,748	87,802
Washington	6,115,867	3,106,412	9,369,903	6,100,928	3,022,950	302.7	46,596		46,596		11,114	13,022	.3	3,825	23,843
West Virginia	4,474,234	2,280,335	6,063,802	4,324,378	1,456,208	205.6	791,054	83,534	651,013	16.9		60,425	.7	66,322	104,689
Wisconsin	9,724,861	4,941,837	15,401,545	9,683,993	4,874,070	619.7	22,678		22,678			21,685		40,888	23,404
Wyoming	4,501,327	2,287,712	6,760,586	4,451,922	2,197,664	1,037.1	5,781	5,780		.3		38,485	.6	43,625	51,562
District of Columbia	1,918,469	973,842	2,740,809	1,909,584	831,090	20.7	137,889		137,889	1.5	8,885				4,863
Hawaii	1,871,062	949,778	2,693,451	1,870,384	264,953	51.1	650,035		647,003	4.7		14,000		678	23,822
TOTALS	394,000,000	200,000,000	614,635,378	386,095,407	173,827,392	34,610.3	25,126,277	4,951,949	17,977,463	714.0	944,683	3,099,233	139.4	2,007,961	5,095,912

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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 9 NOVEMBER 1936

ON STATE ROUTE 50 IN NEW YORK

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 17, No. 9 November 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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THE NEW YORK FINANCIAL SURVEY

DIGEST OF A SURVEY OF THE FINANCES OF NEW YORK IN 1932, WITH SPECIAL REFERENCE TO HIGHWAYS[1]

Reported by **ELIZABETH C. PADDOCK**, Assistant Highway Engineer-Economist, Division of Control, Bureau of Public Roads

IN 1934 a legislative committee was appointed in New York to make a survey of road and traffic conditions in order to assist in determining "future policy with respect * * * to the construction of streets, roads, highways, and footpaths" and "to ascertain the facts with regard to volume, character, and distribution of traffic on streets, and on primary, secondary, and tertiary roads."[2] It was deemed essential "that an economic survey be made to reveal sources of highway revenues to the end that road construction, both rural and urban, may be considered in accordance with the facts and funds equitably distributed for street and highway purposes."[2]

Prior to the initiation of the survey by this legislative committee the Bureau of Public Roads had been conducting investigations in a few other States similar to those desired by New York. Under a cooperative agreement the Bureau assisted the committee in the collection of the desired financial and road-use data. The financial and road-use surveys conducted in New York were modeled after those made in Wisconsin, Illinois, Michigan, Minnesota, New Hampshire, Colorado, Wyoming, and New Mexico.[3] Similar studies are a part of the State-wide highway planning surveys currently being conducted by the Bureau in cooperation with about 40 of the various States.

The same general definitions and methods of collecting and analyzing data have been used in all the surveys. Four main processes characterize each study:

1. *Collection of data.*—In New York this step involved the detailed study of all available records in State offices, personal visits to many counties and localities, and the circulation of about 150,000 questionnaires. The process was simplified to a large extent in New York by the existence in State offices of complete records for all units of government with the exception of Rochester, Buffalo, New York City, and most of the special districts.
2. *Analysis of data.*—Much of the analysis was done as the data were collected. Where special problems of interpretation arose, however, decisions were made only after consultation with officials of the governmental agency in question.
3. *Tabulation of material.*—Detailed tabulations showing all data for the several population classifications in each county were made for the entire State. These tabulations formed the basis for the summary tables presented in this report.
4. *Preparation of report.*—An interpretation of the tabulations provided the material for this summary.

Six primary definitions are basic to an understanding and proper interpretation of the figures compiled for this survey. The term "highways" includes all items having to do with the construction, maintenance, marking, signing, and administration of all roads, streets, alleys, and bridges. The term includes all items pertaining to the keeping of roads and streets in a usable and safe condition for vehicular traffic, but such items as sidewalks, sanitary sewers, ornamental lighting, and street cleaning are excluded.

Activities having to do with the construction, maintenance, and administration of and all teaching in public schools, libraries, and museums are classed as "education."

"Public benefit" consists of all items having to do with the protection of lives and property and with the pleasure and well-being of the people, including police and fire protection, courts, sanitation, parks, playgrounds, and charitable and penal institutions.

All general administration and such other activities as do not fall into one of the three classifications given above are classed as "government."

The definition of "expenditure" as used in this survey is synonymous with the net cost which must be met from public revenue funds, including special assessment payments.

Every payment made to a public body through the authority vested in it to collect funds is an "impost." Thus fees, fines, permits, and licenses are imposts. Where there occurs a difference in the amount of impost levied and the amount collected, the levy is shown.

OVER HALF OF THE TOTAL POPULATION AND PROPERTY VALUATION WAS IN NEW YORK CITY

In an effort to place all the surveys on a comparable basis the same population classification is used.

"Rural areas" are all rural territories outside of incorporated places. In New York all such areas are under town government. "Urban" areas are incorporated villages and cities and are grouped according to population as follows:

Places under 2,500 persons.
Places 2,500 to 14,999 persons.
Places 15,000 to 74,999 persons.
Places 75,000 to 399,999 persons.
Places 400,000 to 999,999 persons.
Places over 1,000,000 persons.

The names of individual cities are used in preference to the last two designations in this report since Buffalo is the only place having 400,000 to 999,999 persons and New York City is the only place having over 1,000,000 persons.

Certain data are basic to a complete understanding of the figures shown by the financial survey and should be kept in mind when reading this summary.

Population concentration in New York State is of more economic and social importance than in many of the other States. The population of New York according to the census of 1930 numbered 12,588,066 persons, more than one-tenth that of the entire continental United States (table 1). This population was crowded into a land area of 45,057 square miles, only 1.6 percent of the total gross area of the United States. Less than 14 percent of the people in New York live in rural areas. A further indication of the population concentration is made evident when it is pointed out that more than 50 percent of the population of the State (6,930,446 persons) live in New York City.

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[1] The full report has been published by the State of New York as Legislative Document (1936) No. 115, vols. I and II. The Bureau of Public Roads does not have copies of the full report for distribution.

[2] Report of the New York State Highway Survey Committee, Legislative Document (1936) No. 89, p. 5.

[3] These financial surveys have been made under the immediate direction of Dr. Henry R. Trumbower, professor of economics at the University of Wisconsin and economist for the Bureau of Public Roads, and H. R. Briggs, field investigator and statistician. For results of the Wisconsin, Illinois, Michigan, Minnesota, and New Hampshire surveys, see the April 1933, May 1933, June 1933, March 1936, and April 1936 issues of PUBLIC ROADS, respectively.

NEW YORK TAXES IN 1932

Total taxes and imposts levied for all purposes in New York in 1932 were $1,212,571,800. Taxation of general property totaled $907,941,700; all motor-vehicle imposts, $81,324,700; other imposts, including estate taxes, personal and business income taxes, bank taxes, and miscellaneous State, county, and local revenues, $223,305,400.

Of the total taxes and imposts levied, rural taxpayers were charged with $116,841,100, or 9.6 percent; residents of incorporated places other than New York City, $362,977,000 or 30 percent; and residents of New York City, $732,753,700 or 60.4 percent.

The average actual tax rates on general property per $100 valuation were as follows: Rural areas, $2.25; incorporated places under 2,500, $1.70; places 2,500 to 14,999, $2.24; places 15,000 to 74,999, $3.18; places 75,000 to 399,999, $3.33; Buffalo, $3.34; and New York City, $2.52.

Rural motor-vehicle owners paid in registration fees and motor-fuel taxes an average of $27.63 per vehicle registered; those resident in incorporated places under 2,500, $28.64; in places 2,500 to 14,999, $30.78; in places 15,000 to 74,999, $31.33; in places 75,000 to 399,999, $33.35; in Buffalo, $31.58; and in New York City, $40.15.

Another factor of economic importance is the valuation of property in the various parts of the State. The figures in table 1 show the full value of property, obtained by dividing the assessed value by the ratio of assessed to full value as determined by the State tax commission. This was necessary to put all valuations on a common basis.

All roads and streets in the State are classed under three general headings for the purposes of this survey. The first group includes the State highway system and any other roads or streets for which State moneys are specifically appropriated, exclusive of State aids or revenue distributions. State and county highways are the main roads included in this designation. The second group includes county roads, administered through the county boards of supervisors, while the third group embraces town highways and city and village streets. Town highways lie entirely outside the limits of incorporated places and are administered by town boards.

The State highway system in 1932 consisted of 12,402 miles, or approximately one-eighth of the total street and road mileage of the State. This mileage is somewhat less than the legal system of State highways as established by the legislature. The system designated by the legislature totaled some 13,947 miles, but for purposes of classification and administration all roads on the designated system are considered to be on the town highway system until they have been improved. Hence, the difference between the two figures given above is equal to the amount of the designated State highway system that was actually maintained by the towns and included in the total mileage of unimproved town highways. Though carried as part of the system designated by the legislature, these roads are actually included in the town highway system in all State reports, programs, and State-aid financing.

OVER 50 PERCENT OF ROADS ON STATE HIGHWAY SYSTEM HAD HIGH-TYPE SURFACES

Table 2 gives in summary form the distribution of the various classes of highways throughout the State in 1932. Table 3 shows that of the total mileage, 15.7 percent was pavement

TABLE 1.—*Population in 1930 and full valuation of taxable real property by class of place in 1932*

Class of place	Population			Full valuation [1]		
	Number	Percent	Per square mile	Amount	Percent	Per capita
Rural areas	1,712,065	13.6	39	$3,558,877,300	10.1	$2,079
Places under 2,500	372,073	3.0	807	1,052,444,600	3.0	2,829
Places 2,500 to 14,999	847,114	6.7	2,354	2,162,089,200	6.2	2,552
Places 15,000 to 74,999	1,004,222	8.0	3,837	2,137,796,300	6.1	2,129
Places 75,000 to 399,999	1,149,070	9.1	7,860	2,794,861,200	8.0	2,432
Buffalo	573,076	4.5	13,580	1,367,211,000	3.9	2,386
New York City	6,930,446	55.1	22,015	22,027,926,000	62.7	3,178
Total	12,588,066	100.0	279	35,101,205,600	100.0	2,788
RECAPITULATION						
Rural	1,712,065	13.6	39	$3,558,877,300	10.1	2,079
Urban	10,876,001	86.4	6,860	31,542,328,300	89.9	2,900
Total	12,588,066	100.0	279	35,101,205,600	100.0	2,788

[1] At State rate of equalization.

TABLE 2.—*Location of the various classes of highways and streets in 1932*

Place where highway was located	State highways		County roads		Local roads and streets		All highways and streets	
	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent
Rural areas	11,507	92.8	11,682	99.0	60,025	78.6	83,214	82.7
Places under 2,500	635	5.1	61	.5	2,619	3.4	3,315	3.3
Places 2,500 to 14,999	246	2.0	51	.4	3,402	4.4	3,699	3.7
Places 15,000 to 74,999	13	.1	12	.1	2,424	3.2	2,449	2.4
Places 75,000 to 399,999					2,047	2.7	2,047	2.0
Buffalo					598	.8	598	.6
New York City	1	([1])			5,270	6.9	5,271	5.3
Total	12,402	100.0	11,806	100.0	76,385	100.0	100,593	100.0
RECAPITULATION								
Rural areas	11,507	92.8	11,682	99.0	60,025	78.6	83,214	82.7
Urban areas	895	7.2	124	1.0	16,360	21.4	17,379	17.3
Total	12,402	100.0	11,806	100.0	76,385	100.0	100,593	100.0

[1] Less than 0.1 percent.

(portland-cement concrete, brick, block, or asphalt) while 42.7 percent was earth. All but 2 miles of the total mileage of earth roads were on the town highway system. More than half of the State highway system was surfaced with portland-cement concrete, brick, block, or asphalt (fig. 1). The county roads in general were of intermediate type with 58.9 percent of their total mileage constructed of mixed bituminous material and 32 percent of water bound macadam and gravel.

Table 4 shows the mileage figures reduced to miles per square mile of area and per thousand persons. Thus, there was 0.27 mile of State highways per square mile of area and 0.99 mile per 1,000 persons, compared with a total on all systems in the State of 2.23 miles of roads and streets per square mile of area and 8 miles per 1,000 persons.

TABLE 3.—*Classification of highways and streets by type of surface in 1932*

BY MILEAGE AND BY PERCENTAGE OF EACH TYPE

Type of surface	State highways		County roads		Local roads and streets		All highways and streets	
	Miles	Percent	Miles	Percent	Miles	Percent	Miles	Percent
High type [1]	6,377	51.4	1,070	9.1	8,338	10.9	15,785	15.7
Mixed bituminous [2]	689	5.6	6,953	58.9	1,352	1.8	8,994	8.9
Surface bituminous [3]	3,875	31.2					3,875	3.9
Water-bound macadam and gravel	1,459	11.8	3,783	32.0	23,738	31.1	28,980	28.8
Earth	2	(4)			42,957	56.2	42,959	42.7
Total [5]	12,402	100.0	11,806	100.0	76,385	100.0	100,593	100.0

BY PERCENTAGE ON EACH SYSTEM

Type of surface	State highways	County roads	Local roads and streets	All highways and streets
High type [1]	40.4	6.8	52.8	100.0
Mixed bituminous [2]	7.7	77.3	15.0	100.0
Surface bituminous [3]	100.0			100.0
Water-bound macadam and gravel	5.0	13.1	81.9	100.0
Earth	(4)		100.0	100.0
Total	12.3	11.7	76.0	100.0

[1] Includes portland-cement concrete, brick, asphalt, and block pavements.
[2] Includes bituminous macadam and other bituminous mixes.
[3] Includes penetration macadam and other low-cost bituminous surfaces.
[4] Less than 0.1 percent.
[5] System as accepted by State—not routes eligible to become State roads.

TABLE 4.—*Mileages of the various classes of roads per square mile of area and per 1,000 persons* [1]

Highway system	Miles per square mile of area	Miles per 1,000 persons
State highways	0.27	0.99
County roads	.26	.94
Local roads and streets	1.70	6.07
All highways and streets	2.23	8.00

[1] Road mileage figures for 1932 were used. Population and area figures for 1930 were used.

State expenditures for highway purposes in 1932 constituted 33.5 percent of the total State expenditures for all purposes. When all units of government of the State are considered, the total expenditures for highways and streets amounted to 15.8 percent of all expenditures. The magnitude of highway expenditures is noteworthy in light of the fact that the functions of the local units of government are more especially concerned with education and public benefit.

Annual expenditures on the State highway system grew steadily from 1924 to 1932. Much of this increase in cost was caused by the enlargement of the system. In 1922 there were but 8,285 miles of improved highways, while there were more than 12,400 miles of improved highways in 1932. Also, the State built almost twice as many miles of highway in 1932 as it did in 1922.

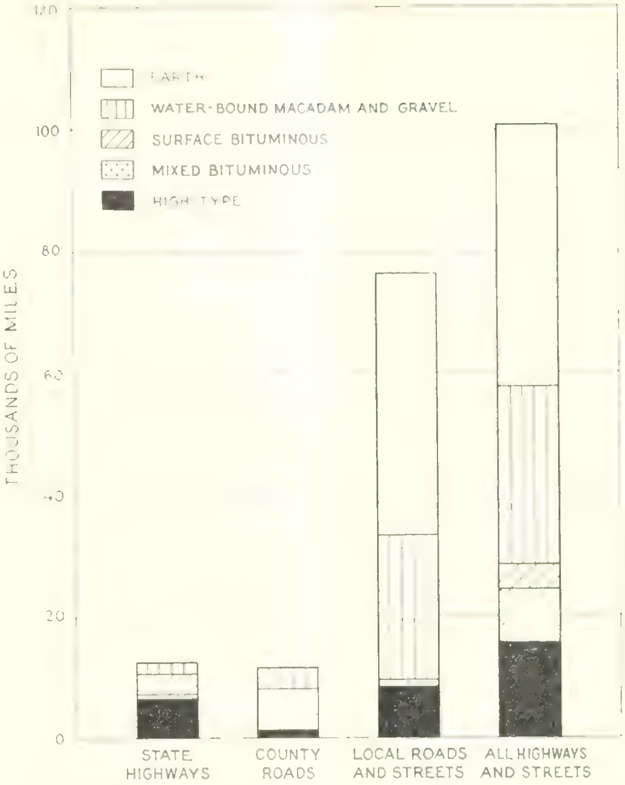

FIGURE 1.—MILEAGE OF ALL HIGHWAYS AND STREETS IN NEW YORK IN 1932, BY TYPES.

Table 5 indicates the considerable drop in expenditures which occurred in 1932. New York, like many other State governments throughout the country, felt in 1930 and 1931 that the economic depression would be of short duration and that its end would be hastened and the unemployed given useful work by the expenditure of large sums of money for public works. The figures for 1932 shown in table 5 are not entirely comparable with those of other years inasmuch as some information available for that year was not available for other years, i. e., expenditures by other agencies, such as the conservation department, for highway purposes. Other items, such as the expenditures by relief organizations, were not significant in the highway expenditures for the years prior to 1932.

$17 PER CAPITA SPENT FOR HIGHWAYS IN 1932

One phenomenon of the 1932 road program in New York was the fact that even though total expenditures dropped more than $16,000,000 from the high of 1931, a considerably greater mileage was constructed and maintained than would normally be expected with such a large decrease in expenditures. This resulted from a decrease in labor costs and material prices and from extremely low bidding by contractors.

The total highway program in New York cost $215,583,200, or $17.13 per capita, in 1932. The extent to which the several units of government participated in the 1932 highway program is shown in table 6. State and county expenditures, allocated to the places where the funds were actually spent, are shown in table 7.

Over 31 percent of the total highway expenditures were made for State highways, and other agencies besides the State made expenditures for the State

TABLE 5.—*Expenditures administered by the State on State highway system, 1924–34*

Year	Construction			Maintenance	Overhead			Grand total
	Highways	Grade crossings[1]	Total		General[3]	Interest	Total	
1924	$23,312,000		$23,312,000	$8,053,600	$1,625,700	$2,847,600	$4,473,300	$35,838,900
1925	26,232,000		26,232,000	9,231,700	2,178,000	2,800,700	4,978,700	40,442,400
1926	27,535,100		27,535,100	9,622,800	2,351,000	2,944,700	5,295,700	42,453,600
1927	37,531,000		37,531,000	11,690,600	1,831,800	3,069,100	4,900,900	54,122,500
1928	39,931,100	$400	39,931,500	12,954,400	1,757,900	3,005,900	4,763,800	57,649,700
1929	44,234,600	1,228,500	45,463,100	14,048,700	2,037,400	2,931,300	4,968,700	64,480,500
1930	48,792,200	5,190,300	53,982,500	14,270,700	2,314,100	2,887,200	5,201,300	73,454,500
1931	56,254,700	4,754,900	61,009,600	13,320,000	2,081,000	3,313,700	5,394,700	79,724,300
1932	38,001,400	6,263,000	44,264,400	13,773,700	1,707,100	3,869,300	5,576,400	[4] 63,614,500
1933	25,416,200	6,963,600	32,379,800	10,636,100	1,512,100	[5] 4,111,800	5,623,900	48,639,800
1934	35,565,400	1,402,200	36,967,600	9,879,200	1,788,500	[5] 4,190,900	5,979,400	52,826,200
Total	399,808,700	28,802,900	428,611,600	127,481,500	21,184,600	35,972,200	57,156,800	613,249,900

[1] Includes grade-crossing expenditures made under supervision of the Division of Highways.
[2] Includes only expenditures in Buffalo, Syracuse, and New York City not administered by Department of Public Works.
[3] Includes operation expense of Bureau of Motor Vehicles of the Department of Taxation and Finance.
[4] Includes $1,152,900 of county and local funds administered by the State.
[5] Approximate.

highway system. These additional expenditures include:

1. Payments by the counties for snow removal on State highways ($645,800).
2. Payments by the counties for right-of-way for new construction or reconstruction projects on State highways ($3,834,000).
3. The contributions to the State for work done on county roads which are part of the State system ($1,152,900).

TABLE 6.—*Total street and highway expenditures as originally made by the several governmental agencies in 1932*

Unit of government making the expenditure	Amount of expenditure	Percent	Expenditure per capita
State	$62,461,600	29.0	$4.96
Counties	43,917,100	20.4	3.49
Towns	22,531,100	10.5	13.16
Places under 2,500	1,729,600	.8	4.65
Places 2,500 to 14,999	4,178,500	1.9	4.93
Places 15,000 to 74,999	4,962,800	2.3	4.88
Places 75,000 to 399,999	5,637,400	2.6	4.96
Buffalo	1,577,000	.7	2.75
New York City	68,587,500	31.8	9.90
Total	215,583,200	100.0	17.13

TABLE 7.—*Total street and highway expenditures as made in each class of place in 1932*

Place where expenditure was made	Amount of expenditure	Percent	Expenditure per capita
Rural areas	$112,585,900	52.2	$65.76
Places under 2,500	4,327,500	2.0	11.63
Places 2,500 to 14,999	6,917,000	3.2	8.17
Places 15,000 to 74,999	6,209,300	2.9	6.18
Places 75,000 to 399,999	10,126,600	4.7	8.81
Buffalo	2,187,600	1.0	3.82
New York City	73,229,300	34.0	10.57
Total	215,583,200	100.0	17.13
RECAPITULATION			
Rural areas	$112,585,900	52.2	$65.76
Urban areas	102,997,300	47.8	9.47
Total	215,583,200	100.0	17.13

A large portion but not all of the State highway expenditures is administered through the Division of Highways. Payments of principal and interest on highway debt are in the hands of the State comptroller. Expenditures for snow removal and the purchase of right-of-way are made by the counties. Certain highway expenditures are made by the Conservation Department, by the emergency-relief commissions, and by various other special commissions such as the Westchester County Parkway Commission. Funds for grade crossing elimination projects in Buffalo, Syracuse, and New York City are controlled by city commissions. The cost of operation of the Bureau of Motor Vehicles, considered in this study as a highway expenditure, is under the supervision of the Department of Taxation and Finance.

One difficulty encountered in this survey was in making the distinction between expenditures for construction and those for maintenance. The State authorities realized that the maintenance accounts included more than maintenance figures and in 1933 changed the system of records so that expenditures for betterments would not appear as general maintenance. In the analysis of the 1932 accounts, maintenance expenditures as shown are not the reported maintenance-fund disbursements but are made up of those items which, as far as could be ascertained, were truly maintenance costs. Table 8 shows expenditures on the several highway systems by the purposes for which they were made, i. e., construction, maintenance, and overhead. The portion expended in or for the benefit of rural areas is given in table 9.

TABLE. 8—*Total expenditures on the several highway systems in 1932*

Purpose of expenditure	State highways	County roads	Local roads and streets	All highways and streets	Percentage of total
Construction:					
Amount	$48,907,900	$33,440,800	$54,398,000	$136,746,700	63.4
Percent	35.8	24.4	39.8	100.0	
Maintenance:					
Amount	$13,635,800	$3,999,800	$41,284,200	$58,919,800	27.3
Percent	23.1	6.8	70.1	100.0	
Overhead:[1]					
Amount	$5,550,600	$843,800	$13,522,300	$19,916,700	9.3
Percent	27.9	4.2	67.9	100.0	
Total:					
Amount	$68,094,300	$38,284,400	$109,204,500	$215,583,200	100.0
Percent	31.6	17.8	50.6	100.0	

[1] Includes interest payments.

ONE-HALF OF ALL HIGHWAY EXPENDITURES WAS FOR LOCAL ROADS AND STREETS

Maintenance expenditures in 1932 compared to those of previous years show considerable increase caused not only by the greater mileage of highways maintained but

TABLE 9.—*Total highway expenditures on all highway systems in rural areas in 1932*

Purpose of expenditure	State highways: Amount	State highways: Percent	County roads: Amount	County roads: Percent	Town roads: Amount	Town roads: Percent	All highways	Percent
Construction:								
Amount	$34,590,600	65.9	$32,773,700	87.3	$6,317,300	28.0	$73,681,600	65.4
Percent	46.9		44.5		8.6		100.0	
Maintenance:								
Amount	$12,782,300	24.4	$3,949,200	10.5	$14,431,000	64.1	$31,162,500	27.7
Percent	41.0		12.7		46.3		100.0	
Overhead: [1]								
Amount	$5,116,300	9.7	$842,700	2.2	$1,782,800	7.9	$7,741,800	6.9
Percent	66.1		10.9		23.0		100.0	
Total:								
Amount	$52,489,200	100.0	$37,565,600	100.0	$22,531,100	100.0	$112,585,900	100.0
Percent	46.6		33.4		20.0		100.0	

[1] Includes interest payments.

also by the fact that in 1932 the Division of Highways performed many functions of maintenance which it did not formerly undertake. The costs of maintenance per mile and per vehicle are shown in table 10.

While the county roads constituted 11.7 percent of the total highway mileage of the State, they carried but 5.9 percent of the total travel performed by New York State residents on all New York roads and streets in 1932. The travel figures, obtained through the road-use survey, indicate the small total travel on county roads. This, however, does not mean that the county roads do not have an important place in the highway system of the State. They are in most cases necessary feeder roads which serve to carry local traffic quickly and cheaply to the State highways and other through routes.

An attempt was made during this survey to determine the amount of county expenditures made for the acquisition of right-of-way for State highways. On the basis of returns to questionnaires received from approximately two-thirds of the county superintendents of highways or from the boards of supervisors, this expenditure was estimated to have been $3,834,000 in 1932. The incidental costs in connection with acquiring the various parcels of land for right-of-way were no inconsiderable portion of the total, amounting to approximately 10 percent for the State as a whole and in some counties running as high as 20 percent of the total.

TABLE 10.—*Per-mile, per-vehicle, and total expenditures for street and highway maintenance in the various places in New York in 1932*

Unit of government where vehicle was registered and where highway expenditure was made	Maintenance expenditures: Expenditure per mile	Maintenance expenditures: Expenditure per vehicle registered	Maintenance expenditures: Total
Rural areas	$374	$59	$31,162,500
Places under 2,500	502	11	1,662,300
Places 2,500 to 14,999	687	10	2,540,300
Places 15,000 to 74,999	897	9	2,197,000
Places 75,000 to 399,999	758	6	1,550,700
Buffalo	980	5	585,800
New York City	365	24	19,221,200
Total	586	25	58,919,800

By legal interpretation the counties are responsible for the maintenance of the State highways between November 15 and May 1, as the highway law provides that the State shall not be liable for damages suffered by any person from defects on State and county highways except between the first day of May and the fifteenth day of November.

Town highways constitute by far the largest mileage in any one class of roads or streets, totaling 60,025 miles or approximately 60 percent of the total mileage of the State. All of this mileage of town highways was in unincorporated areas and more than two-thirds of it was unsurfaced in 1932. The road-use survey shows that town highways carried an average of 8,410 vehicles per mile per year, or but 23 vehicles per mile per day. There are, of course, sizeable areas, adjacent to incorporated places, where town highways are of considerable importance, and the traffic on town highways in densely populated areas is much heavier than the average figure indicates.

Table 9 shows that in 1932 more than $22,500,000 was expended on the town highways of New York, or more than $370 on each mile of the system.

The total city and village street mileage in the State was more than either the county road or the State highway mileage, totaling 16,360 miles. Of this, 35.4 percent was in the city of New York. Forty percent of all highway expenditures in the State was made by urban communities. The State and counties spent $16,323,900 on routes in urban places, and the total highway expenditure was $102,997,300 in these communities.

A distinction is made in these surveys between the taxes imposed specifically for highway purposes and those imposts which are eventually used for roads and streets. The practice in most communities is to place the proceeds from all imposts into a general fund on which vouchers are drawn for all purposes. Highways are supported by the several types of imposts, therefore, in the same ratio that the proceeds from these imposts bear to the total income of the unit of government. More than half of the amount necessary to pay for the total highway costs in 1932 was raised from specific highway taxes which amounted to $10.13 per capita or $55.52 per vehicle (table 11). Over one-third of this amount was raised by levies on property. The towns of New York are the only units of government that levy specific highway taxes on property, with the exception of special assessments levied on property benefited in the several villages and cities of the State.

Tables 12 and 13 and figure 2 indicate that half of the cost of State highways was financed by motor-vehicle imposts. In addition, almost $17,000,000 of loans and reserves and $11,401,700 of Federal aid were necessary to meet these costs. Table 12 gives the breakdown of the amount spent out of current receipts into payments by taxpayers and motor-vehicle owners in the several classes of local units, and thus shows the contributions by each of these classes to the expenditures on the several highway systems and local streets.

EXPENDITURES FOR ALL PURPOSES AMOUNTED TO $108 PER CAPITA

The presentation of highway data alone does not give an indication of the importance of this activity among all functions of the various governmental agencies. It is necessary to show the cost of all governmental operations and the various sources from which imposts are derived to pay for the activities.

Tax, expenditure, and debt data are shown in two ways:

1. By unit of government levying the tax, making the expenditure, or incurring the debt.
2. By actual incidence of tax payment, expenditures made, and debt liability. This applies not only

TABLE 11.—*Specific highway taxes levied for collection, in 1932, by class of place where tax was paid*

AMOUNTS OF IMPOSTS

Class of place where tax was paid	General property tax	Special assessments	Motor-fuel tax	Registration fees	Miscellaneous charges [1]	Total
Rural areas	$13,044,600		$6,144,200	$6,246,700	$615,700	$26,051,200
Places under 2,500	549,500	$302,300	2,099,800	2,158,800	212,600	5,323,000
Places 2,500 to 14,999	489,600	399,900	3,956,000	4,137,300	409,000	9,391,800
Places 15,000 to 74,999	54,200	905,100	3,899,000	3,846,300	385,400	9,090,000
Places 75,000 to 399,999		4,232,500	4,697,200	4,163,000	402,600	13,495,300
Buffalo		455,300	2,017,100	1,960,800	183,600	4,616,800
New York City		25,727,700	17,527,600	14,474,100	1,787,900	59,517,300
Total	14,137,900	32,022,800	40,340,900	36,987,000	3,996,800	[2] 127,485,400

PERCENTAGE, PER-CAPITA, AND PER-VEHICLE DISTRIBUTION OF IMPOSTS

	General property tax	Special assessments	Motor-fuel tax	Registration fees	Miscellaneous charges [1]	Total
Percentage of total	11.1	25.1	31.7	29.0	3.1	100.
Amount per capita	$1.12	$2.54	$3.21	$2.94	$0.32	$10.13
Amount per vehicle	6.16	13.95	17.57	16.11	1.73	55.52

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[1] Drivers' licenses, transfers, etc.

[2] An additional $237,800 was derived from nonresidents. This amount was composed of $206,900 registration fees and $30,900 miscellaneous charges.

TABLE 12.—*Approximate amounts of the 1932 taxes and imposts expended on New York highways listed according to highway system, type of tax, and class of local unit by which the tax was paid*

PROPERTY TAXES

Paid by residents of—	State highways		County roads		Local roads and streets		All highways and streets		Percentage of total
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	
Rural areas	$1,780,000	5.7	$9,269,200	29.4	$20,436,700	64.9	$31,485,900	100.0	
Places under 2,500	416,700	6.8	2,170,600	35.4	3,550,000	57.8	6,137,300	100.0	
Places 2,500 to 14,999	906,900	7.3	4,722,600	38.3	6,716,300	54.4	12,345,800	100.0	
Places 15,000 to 74,999	929,400	7.4	4,840,000	38.5	6,812,200	54.1	12,581,600	100.0	
Places 75,000 to 399,999	980,100	6.0	5,104,000	31.4	10,170,400	62.6	16,254,500	100.0	
Buffalo	619,600	8.5	3,226,600	44.2	3,454,100	47.3	7,300,300	100.0	
New York City					44,807,300	100.0	44,807,300	100.0	
Total	[1] 5,632,700	4.3	29,333,000	22.4	95,947,000	73.3	130,912,700	100.0	60.7

MOTOR-VEHICLE IMPOSTS

Paid by residents of—	State highways		County roads		Local roads and streets		All highways and streets		Percentage of total
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	
Rural areas	$5,456,100	65.0	$1,368,400	16.3	$1,573,100	18.7	$8,397,600	100.0	
Places under 2,500	1,875,500	65.0	470,400	16.3	540,800	18.7	2,886,700	100.0	
Places 2,500 to 14,999	3,580,500	65.0	897,900	16.3	1,032,400	18.7	5,510,800	100.0	
Places 15,000 to 74,999	3,410,000	65.0	855,200	16.3	983,200	18.7	5,248,400	100.0	
Places 75,000 to 399,999	3,887,400	65.0	975,000	16.3	1,120,900	18.7	5,983,300	100.0	
Buffalo	1,807,300	65.0	453,300	16.3	521,100	18.7	2,781,700	100.0	
New York City	14,083,500	65.0	3,532,100	16.3	4,060,700	18.7	21,676,300	100.0	
Total	34,100,300	65.0	8,552,300	16.3	9,832,200	18.7	52,484,800	100.0	24.3

OTHER IMPOSTS

Paid by residents of—	State highways		County roads		Local roads and streets		All highways and streets		Percentage of total
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	
Rural areas			$120,900	33.8	$236,300	66.2	$357,200	100.0	
Places under 2,500			26,800	34.3	51,400	65.7	78,200	100.0	
Places 2,500 to 14,999			59,500	27.9	154,100	72.1	213,600	100.0	
Places 15,000 to 74,999			71,000	23.6	229,500	76.4	300,500	100.0	
Places 75,000 to 399,999			81,000	20.3	318,600	79.7	399,600	100.0	
Buffalo			39,900	20.9	150,700	79.1	190,600	100.0	
New York City					2,284,700	100.0	2,284,700	100.0	
Total			399,100	10.4	3,425,300	89.6	3,824,400	100.0	1.8

ALL TAXES AND IMPOSTS

Paid by residents of—	State highways		County roads		Local roads and streets		All highways and streets		Percentage of total
	Amount	Percent	Amount	Percent	Amount	Percent	Amount	Percent	
Rural areas	$7,236,100	18.0	$10,758,500	26.7	$22,246,100	55.3	$40,240,700	100.0	
Places under 2,500	2,292,200	25.2	2,667,800	29.3	4,142,200	45.5	9,102,200	100.0	
Places 2,500 to 14,999	4,487,400	24.8	5,680,000	31.4	7,902,800	43.8	18,070,200	100.0	
Places 15,000 to 74,999	4,339,400	23.9	5,766,200	31.8	8,024,900	44.3	18,130,500	100.0	
Places 75,000 to 399,999	4,867,500	21.5	6,160,000	27.2	11,609,900	51.3	22,637,400	100.0	
Buffalo	2,426,900	23.6	3,719,800	36.2	4,125,900	40.2	10,272,600	100.0	
New York City	14,083,500	20.5	3,532,100	5.1	51,152,700	74.4	68,768,300	100.0	
Total	39,733,000	21.2	38,284,400	20.5	109,204,500	58.3	187,221,900	100.0	86.8
Federal aid	11,401,700	100.0					11,401,700	100.0	5.3
Loans and reserves	16,959,600	100.0					16,959,600	100.0	7.9
Grand total	68,094,300	31.6	38,284,400	17.8	109,204,500	50.6	215,583,200	100.0	100.0

[1] Arises from county participation in financing right-of-way and certain other costs in connection with State roads.

to State and county data but also to the taxes levied, expenditures made, and debt incurred by the town governments. Their taxes are generally a levy on the village residents as well as on the residents of the rural areas of the town because villages are a part of the town in which they are located.

In the State as a whole, $1,362,616,300, or $108 per resident, was spent for all activities of the State, counties, and local governments (fig. 3). Of this amount, $17 per capita was the cost of highways. Twenty-nine percent of the highway expenditure was made by the State, 20.4 percent by the counties, and 50.6 percent by the local governments. Expenditures by the State for education were only 3.6 percent of the total for all governmental units, those for public benefit 13.8 percent, and those for government 14.2 percent.

Public benefit costs accounted for over 55 percent of the expenditures for all purposes by all governmental agencies. Nearly 79 percent of these expenditures was made by the local units of government. Educational activities were almost entirely a matter of local concern, with 96.4 percent of the expenditures for this purpose being made by the towns, villages, cities, and school districts. The county expenditures for education were almost negligible, amounting to only 1 cent per capita, while the State spent about $1 per capita for these activities.

Table 14 shows that the local units of government—the towns, villages, cities, school districts, and special districts—spent more per capita than did the counties and State. The State and counties made most of their expenditures for public benefit and highways. Expenditures by the local units of government for public benefit were also large, but education costs replaced those of highways as second largest in amount.

Most of the highway expenditures by the State and the counties were made in the rural areas. Added to these expenditures were those made by the local units of government in their respective areas, bringing the total expenditures for highways in the rural areas to $112,585,900, or $66 per capita. Highway expenditures in the urban areas were $102,997,300, or $9.47 per capita.

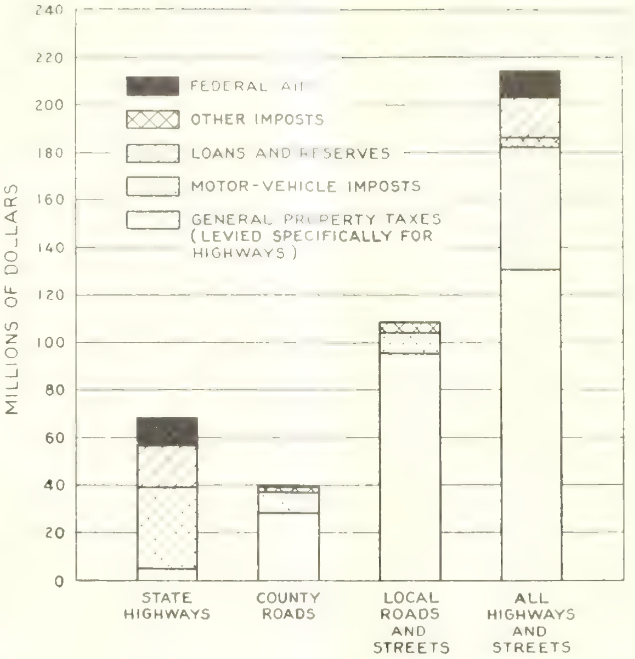

FIGURE 2.—DISTRIBUTION OF TOTAL EXPENDITURES FOR HIGHWAYS AND STREETS, SHOWING SOURCES OF FUNDS.

Practically all of the other expenditures made by the State and the counties were made for the residents of the State in general proportion to the population distribution (table 15). Public benefit and education expenditures in the urban areas were more per capita than in the rural areas. This is true because urban communities maintain more expensive educational equipment and provide more secondary schools than

TABLE 13.—*Funds expended on highways and streets in New York in 1932 and the approximate amounts and percentages of these funds provided by imposts and by loan and reserve funds, as made by the various governmental units*

Highway system	Governmental agency providing funds					Percentage of total current tax funds	Percentage of total funds
	Federal	State	County	Local	Total		
State highways:							
Loans and reserves		[1] $16,959,600			$16,959,600		
Current taxes	$11,401,700	34,100,300	$5,632,700		51,134,700	25.7	
Total	11,401,700	51,059,900	5,632,700		68,094,300		31.6
Percentage of total	16.7	75.0	8.3		100.0		
County roads:							
Loans and reserves							
Current taxes		$8,951,400	$29,333,000		$38,284,400	19.3	
Total		8,951,400	29,333,000		38,284,400		17.8
Percentage of total		23.4	76.6		100.0		
Local roads and streets:							
Loans and reserves							
Current taxes		$13,257,500		$95,947,000	$109,204,500	55.0	
Total		13,257,500		95,947,000	109,204,500		50.6
Percentage of total		12.1		87.9	100.0		
All highways and streets:							
Loans and reserves		$16,959,600			$16,959,600		
Current taxes	$11,401,700	56,309,200	$34,965,700	$95,947,000	198,623,600	100.0	
Total	11,401,700	73,268,800	34,965,700	95,947,000	215,583,200		100.0
Percentage of total	5.3	34.0	16.2	44.5	100.0		

[1] Includes proceeds of general State improvement bonds and notes as of Dec. 31, 1932, and grade crossing elimination bonds and notes as of June 30, 1933, and grade crossing elimination funds used as of June 30, 1933.

[2] Report of the State tax commission, 1932, and annual report of the department of audit and control, June 30, 1933.

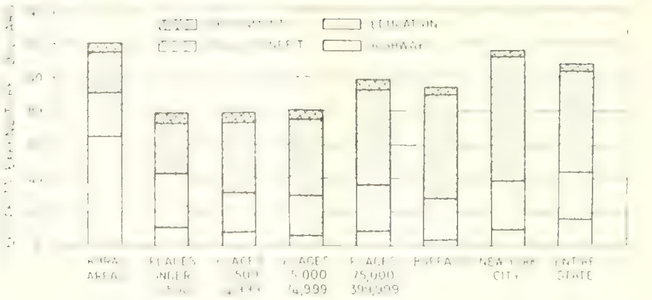

Figure 3.—Per-Capita Expenditures for Different Purposes, Distributed by Governmental Units in or for Which Expenditures Were Made.

do rural areas, and also support many institutions not necessary in the rural areas.

The effect that New York City has on the activities of the entire State and the proportion that the expenditures of this one city bear to the total for the State are illustrated by the fact that of all expenditures, 59.5 percent was made in or for the benefit of the residents of New York City.

Table 14.—*Expenditures by all units of government in New York for various purposes, in 1932*

Expenditures made by	Total expenditures	Percent	Per-capita expenditures for Highways	Education	Public benefit	Government	Total
State	$186,429,300	13.7	$4.96	$0.97	$8.28	$0.60	$14.81
Counties	110,312,200	8.1	3.49	.01	4.64	.62	8.76
Towns	85,985,500	6.3	13.16	23.84	9.82	3.40	50.22
Places under 2,500	17,268,600	1.3	4.65	30.63	9.00	2.13	46.41
Places 2,500 to 14,999	40,817,500	3.0	4.93	22.50	17.83	2.92	48.18
Places 15,000 to 74,999	57,170,400	4.2	4.88	22.91	26.72	2.72	57.23
Places 75,000 to 399,999	84,816,700	6.2	4.96	26.01	38.76	4.08	73.81
Buffalo	42,074,100	3.1	2.75	23.51	44.81	2.35	73.42
New York City	737,142,000	54.1	9.90	27.28	66.29	2.94	106.41
Total	1,362,616,300	100.0	17.13	26.93	59.93	4.26	108.25
RECAPITULATION							
State	$186,429,300	13.7	$4.96	$0.97	$8.28	$0.60	$14.81
Counties	110,312,200	8.1	3.49	.01	4.64	.62	8.76
Local governments	1,065,874,800	78.2	8.68	25.95	47.01	3.04	84.68
Total	1,362,616,300	100.0	17.13	26.93	59.93	4.26	108.25

Table 15.—*Expenditures by State, counties, and local governments for various purposes, showing unit of government in or for which expenditure was made in 1932*

Expenditures made in or for residents of—	Total expenditures	Percent	Per-capita expenditures for— Highways	Education	Public benefit	Government	Total
Rural areas	$206,827,400	15.2	$65.76	$24.83	$25.92	$4.30	$120.81
Places under 2,500	29,607,100	2.2	11.63	31.60	30.43	5.91	79.57
Places 2,500 to 14,999	67,266,300	4.9	8.17	23.48	41.50	6.26	79.41
Places 15,000 to 74,999	80,561,000	5.9	6.18	23.88	45.26	4.90	80.22
Places 75,000 to 399,999	114,071,900	8.4	8.81	27.02	57.45	5.99	99.27
Buffalo	53,952,800	3.9	3.82	24.54	61.53	4.26	94.15
New York City	810,329,800	59.5	10.57	28.25	74.56	3.54	116.92
Total	1,362,616,300	100.0	17.13	26.93	59.93	4.26	108.25
RECAPITULATION							
Rural areas	$206,827,400	15.2	$65.76	$24.83	$25.92	$4.30	$120.81
Urban areas	1,155,788,900	84.8	9.47	27.26	65.28	4.26	106.27
Total	1,362,616,300	100.0	17.13	26.93	59.93	4.26	108.25

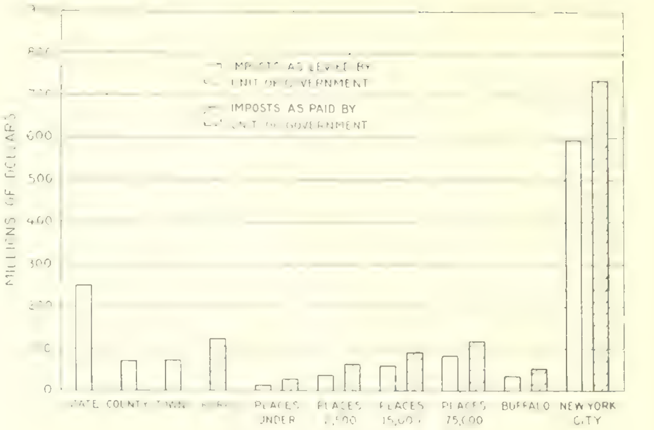

Figure 4.—Imposts as Levied and as Paid by the Several Units of Government of New York in 1932.

LOCAL UNITS OF GOVERNMENT LEVIED 74 PERCENT OF ALL IMPOSTS

Tables 16 and 17 and figure 4 give a comparison between the imposts levied by a unit of government and the taxes which its residents must pay. From these tables the proportion that each kind of impost levied—property, motor-vehicle, other taxes, and miscellaneous imposts—bears to the total of all taxes can be seen. Thus, of the total of $96 per capita which residents of New York paid to the State, counties, and local units of government in taxes, $20 or 20.5 percent was levied by the State and $6 or 5.8 percent by the counties, while the local units levied the remainder, $71 or 73.7 percent. It is evident that the local units of government created the largest tax bill in the levy of imposts for carrying out of their own local functions. In this respect, New York City was highest with $86 per capita.

The State obtained little of its income from the general property tax. The court stenographers' and armory taxes were levies on general property, but the proceeds were distributed to the counties and judicial districts of the State and were not used for State purposes. The greatest share of State imposts came from motor-vehicle and other imposts, such as personal

Table 16.—*Total and per-capita amounts of imposts levied by the several units of government in 1932*

Levied by	Total of all imposts	Percent	Imposts per capita Property taxes	Motor-vehicle imposts	Other taxes	Miscellaneous	Total
State	$248,519,600	20.5	$0.08	$6.46	$13.20	...	$19.74
Counties	70,952,400	5.8	5.24		...	$0.40	5.64
Towns	66,474,200	5.5	37.26		...	1.57	38.83
Places under 2,500	12,096,600	1.0	30.89			1.62	32.51
Places 2,500 to 14,999	37,424,700	3.1	41.40			2.78	44.18
Places 15,000 to 74,999	59,210,700	4.9	56.36	...		2.60	58.96
Places 75,000 to 399,999	83,210,700	6.9	70.82			1.60	72.42
Buffalo	39,153,100	3.2	66.86			1.46	68.32
New York City	595,529,800	49.1	79.97			5.96	85.93
Total	1,212,571,800	100.0	72.13	6.46	13.20	4.54	96.33
RECAPITULATION							
State	$248,519,600	20.5	$0.08	$6.46	$13.20	...	$19.74
Counties	70,952,400	5.8	5.24		...	$0.40	5.64
Local governments	893,099,800	73.7	66.81			4.14	70.95
Total	1,212,571,800	100.0	72.13	6.46	13.20	4.54	96.33

TABLE 17.—*Total and per-capita amounts of imposts as finally paid by the residents of the several classes of places in 1932*

Paid by residents of	Total of all imposts	Percent	Imposts per capita				
			Property taxes	Motor-vehicle imposts	Other taxes	Miscellaneous income	Total
Rural areas	$116,841,100	9.6	$46.87	$7.60	[illegible]	[illegible]	$68.25
Places under 2,500	27,556,300	2.3	18.02	12.02	11.13	[illegible]	74.06
Places 2,500 to 14,999	71,019,700	5.9	57.24	10.61	[illegible]	[illegible]	83.84
Places 15,000 to 74,999	90,581,400	7.4	67.79	[illegible]	10.8[illegible]	3.24	90.00
Places 75,000 to 399,999	117,028,100	9.6	80.98	[illegible]	[illegible]	[illegible]	101.85
Buffalo	56,991,500	4.7	79.72	7.62	9.33	2.78	99.45
New York City	732,753,700	60.4	80.01	1.85	14.91	5.96	105.73
Total	1,212,571,800	100.0	72.13	6.46	13.20	4.54	96.33

RECAPITULATION

Paid by residents of	Total of all imposts	Percent	Property taxes	Motor-vehicle imposts	Other taxes	Miscellaneous income	Total
Rural areas	$116,841,100	9.6	$46.87	$7.60	[illegible]	[illegible]	$68.25
Urban areas	1,095,730,700	90.4	76.10	6.28	13.51	4.86	100.75
Total	1,212,571,800	100.0	72.13	6.49	13.20	4.51	96.33

TABLE 18.—*Property tax rates per $100 valuation and their relation to the total of all imposts in 1932*

Paid by residents of	Actual tax rate on property	Tax rate needed to raise all taxes by property levies	Percentage that property taxes are of all imposts
Rural areas	$2.25	$3.28	68.7
Places under 2,500	1.70	2.62	64.8
Places 2,500 to 14,999	2.21	[illegible]	68.3
Places 15,000 to 74,999	3.18	4.23	[illegible]
Places 75,000 to 399,999	3.33	[illegible]	[illegible]
Buffalo	3.34	4.18	80.4
New York City	2.52	3.33	75.7
Average for State	2.59	3.47	74.9

and business income taxes, estate taxes, and bank taxes.

All but 7 percent of the county taxes in 1932 were derived from the property tax. The local units of government levied $840,890,200 in property taxes or over 94 percent of their total imposts. In addition to these imposts received by the counties and the local units of government, there was available for their use the funds supplied by Federal and State grants and aids. That is, while the State levied and administered $248,519,600 in taxes, a large share of this amount was distributed among the counties and localities in the form of aids, and only a relatively small portion was used for State purposes exclusively.

NEW YORK EXPENDITURES IN 1932

The total expenditures for all purposes (exclusive of principal payments on bonds and loans) by all units of government in 1932 were $1,362,616,300, of which $215,583,200 was expended for highways and streets, $339,026,700 for education, $754,353,700 for public benefit, and $53,652,700 for other governmental purposes.

Expenditures by the State were $186,429,300; by the counties, $110,312,200; by New York City, $737,442,000; by other incorporated places, $242,447,300; and by the towns, $85,985,500.

Of the total expenditures, 15.2 percent was made in rural areas; 25.3 percent in incorporated places other than New York City; and 59.5 percent in New York City.

Motor-vehicle imposts were levied only by the State government, and they totaled $81,324,700 or nearly 7 percent of the imposts of all units of government from all sources.

All State and county levies are eventually paid by the residents of either rural or urban areas of the State. Thus, the imposts received by the State and counties were distributed among the local units of government in the approximate amounts which they were responsible for paying to the larger governmental units. In New York City, for example, which levied imposts in the amount of $85.93 per capita, an additional $19.80 was collected from its residents in order to pay the State imposts levied against the area.

Table 18 and figure 5 are of special significance, as they give a comparison between the tax rates on property and the rates applicable if all imposts were derived from a property levy. As an example of the facts presented in the table, the actual tax rate on property because of property levies in the rural areas was $2.25 per $100 of full value. If all imposts had been obtained from a property levy, property would have had to pay $3.28 per $100 of value.

It is also evident that in the State as a whole the property levies constituted the major source of revenue—74.9 percent. The ratio of property levies to total imposts was highest in Buffalo where 80.4 percent of the revenues was derived from the taxes on property.

Table 19 and figure 6 show relations between the taxes paid by a community and the expenditures made in or for the benefit of the community by State, county, and local governments. In rural areas, incorporated places under 2,500, and in New York City, expenditures by and for the community exceeded the taxes paid. In the other incorporated places expenditures ranged from 89 to 97 percent of taxes paid. For the State as a whole expenditures exceeded taxes. This situation was due in a large measure to the financing by borrowings necessitated primarily by heavy expenditures for relief.

TABLE 19.—*Imposts paid by and expenditures made in or for the benefit of residents of the several classes of places in 1932*

Place	Imposts			Expenditures			Ratio of expenditures to taxes
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	
Rural areas	$116,841,100	9.6	$68.25	$206,827,400	15.2	$120.81	1.77
Places under 2,500	27,556,300	2.3	74.06	29,607,100	2.2	79.57	1.07
Places 2,500 to 14,999	71,019,700	5.9	83.84	67,266,300	4.9	79.41	.95
Places 15,000 to 74,999	90,581,400	7.4	90.00	80,561,000	5.9	80.22	.89
Places 75,000 to 399,999	117,028,100	9.7	101.85	114,071,900	8.4	99.27	.97
Buffalo	56,991,500	4.7	99.45	53,952,800	3.9	94.15	.95
New York City	732,753,700	60.4	105.73	810,329,800	59.5	116.92	1.11
Total	1,212,571,800	100.0	96.33	1,362,616,300	100.0	108.25	1.12

RECAPITULATION

Place	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Ratio of expenditures to taxes
Rural areas	$116,841,100	9.6	$68.25	$206,827,400	15.2	$120.81	1.77
Urban areas	1,095,730,700	90.4	100.75	1,155,788,900	84.8	106.27	1.05
Total	1,212,571,800	100.0	96.33	1,362,616,300	100.0	108.25	1.12

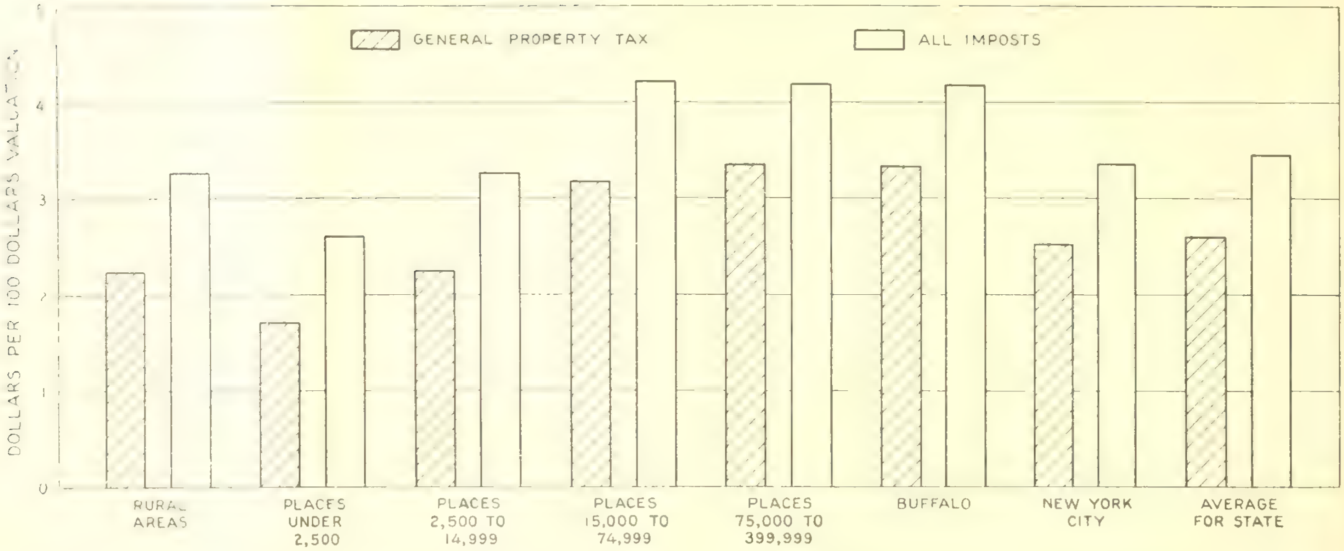

Figure 5.—Actual Tax Rates on General Property in the Several Classes of Places, and Rates Needed to Raise all Taxes by Property Levies.

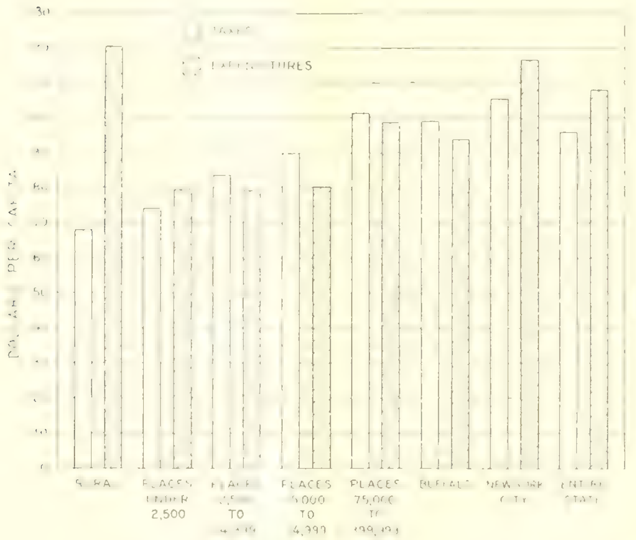

Figure 6.—Per-Capita Taxes Paid by and Expenditures Made for Residents of the Several Units of Government by all Governmental Agencies in New York in 1932.

LOCAL UNITS OF GOVERNMENT MADE 78 PERCENT OF ALL GOVERNMENTAL EXPENDITURES

Tables 20, 21, and 22 give the amounts of taxes levied and expenditures made by the local communities in relation to similar transactions for the community by the State and county. For example, 53 percent of the taxes paid by residents of the rural areas were levied by the local governments and 47 percent by the State and county (table 20). Of the $206,827,400 of expenditures made in or for the benefit of rural residents, however, 61.6 percent was by State and county and 38.4 percent by the local unit of government itself.

The primary debt and debt service data for New York in 1932 are summarized in tables 23, 24, and 25. Of particular importance are the following facts:

1. Over one-half (53.5 percent) of the outstanding debt was originally incurred for public benefit purposes.

2. New York City itself had outstanding over one-half (58.4 percent) of the entire debt incurred by all units of government and was liable for the payment of 66.5 percent of all debt.

3. Local debt for public benefit constituted 55.5 percent of the total local debt outstanding.

4. The outstanding debt per capita for all purposes was $299.94, of which $240.71 was local debt.

5. Rural areas (which incurred 4.4 percent of the outstanding debt) were liable for the payment of 7.7 percent of the total debt.

6. Interest and principal payments on short-term debt constituted 74.1 percent of all debt-service costs.

7. Interest payments were but 12.9 percent of the debt service costs; retirements constituted the remaining 87.1 percent.

The incidence of motor-vehicle imposts was determined by an analysis of over 100,000 registration applications and the replies to as many questionnaires distributed to motor-vehicle owners throughout the State. In the analysis the data from the State motor-vehicle bureau were grouped under the following designations: "Cars" include passenger cars, taxis, and the majority of dealer registrations; "trucks and busses" consist of busses (from the State omnibus classification), commercial vehicles, ambulances, suburban cars, and a small number of vehicles with dealer licenses; trailers and motorcycles are "other" vehicles.

The New York motor-vehicle bureau licensed 2,302,259 vehicles[4] in 1932, of which 6,196 vehicles were registered by nonresidents. The residents of New York State, therefore, procured licenses for 2,296,063 vehicles. Most of the vehicles registered were cars—84.3 percent (table 26). The proportion of cars to trucks remained fairly constant except in the rural areas where, as would be expected, there were relatively more trucks than in the urban areas. In rural areas a truck is often the only vehicle owned, serving both as pleasure and business vehicle. Or if a passenger car is owned, a truck is usually also necessary.

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[4] This registration figure differs from a previous figure released by the Bureau because of inaccuracies in the figures originally reported by the State.

TABLE 20.—*Imposts paid by and expenditures made in or for the benefit of residents of rural areas in 1932*

CLASSIFICATION OF TAXES AND GOVERMENTAL UNIT LEVYING THEM

Item	State and county			Local government			All governments		
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
IMPOST									
Property:									
Amount	$21,061,700	38.3	$12.30	$59,189,200	95.7	$34.57	$80,250,900	68.7	$46.87
Percent	26.2			73.8			100.0		
Motor vehicle:									
Amount	$13,006,600	23.7	7.60				$13,006,600	11.1	7.60
Percent	100.0						100.0		
Other:									
Amount	$20,903,900	38.0	12.21	$2,679,700	4.3	1.57	$23,583,600	20.2	13.78
Percent	88.6			11.4			100.0		
Total:									
Amount	$51,972,200	100.0	32.11	$61,868,900	100.0	36.14	$116,841,100	100.0	68.25
Percent	47.0			53.0			100.0		

CLASSIFICATION OF EXPENDITURES BY PURPOSE AND BY GOVERMENTAL UNIT MAKING THEM

Item	State and county			Local government			All governments		
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
EXPENDED FOR									
Highways:									
Amount	$90,054,800	70.7	$52.60	$22,531,100	28.3	$13.16	$112,585,900	54.4	$65.76
Percent	80.0			20.0			100.0		
Education:									
Amount	$1,686,400	1.3	.99	$40,815,000	51.4	23.84	$42,501,400	20.5	24.83
Percent	4.0			96.0			100.0		
Public benefit:									
Amount	$32,099,300	25.2	18.75	$12,270,100	15.4	7.17	$44,369,400	21.5	25.92
Percent	72.3			27.7			100.0		
Government:									
Amount	$3,512,300	2.8	2.05	3,858,400	4.9	2.25	$7,370,700	3.6	4.30
Percent	47.7			52.3			100.0		
Total:									
Amount	$127,352,800	100.0	74.39	$79,474,600	100.0	46.42	$206,827,400	100.0	120.81
Percent	61.6			38.4			100.0		

TABLE 21.—*Imposts paid by and expenditures made in or for the benefit of residents of urban areas in 1932*

CLASSIFICATION OF TAXES AND GOVERNMENTAL UNIT LEVYING THEM

Item	State and county			Local government			All governments		
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
IMPOST									
Property:									
Amount	$45,989,800	17.4	$4.23	$781,701,000	94.0	$71.87	$827,690,800	75.6	$76.10
Percent	5.6			94.4			100.0		
Motor vehicle:									
Amount	$68,318,100	25.8	6.28				$68,318,100	6.2	6.28
Percent	100.0						100.0		
Other:									
Amount	$150,191,900	56.8	13.81	$49,529,900	6.0	4.56	$199,721,800	18.2	18.37
Percent	75.2			24.8			100.0		
Total:									
Amount	$264,499,800	100.0	24.32	$831,230,900	100.0	76.43	$1,095,730,700	100.0	100.75
Percent	24.1			75.9			100.0		

CLASSIFICATION OF EXPENDITURES BY PURPOSE AND BY GOVERNMENTAL UNIT MAKING THEM

Item	State and county			Local government			All governments		
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
EXPENDED FOR									
Highways:									
Amount	$16,323,900	9.6	$1.50	$86,673,400	8.8	$7.97	$102,997,300	8.9	$9.47
Percent	15.8			84.2			100.0		
Education:									
Amount	$10,602,700	6.3	.97	$285,922,600	29.0	26.29	$296,525,300	25.7	27.26
Percent	3.6			96.4			100.0		
Public benefit:									
Amount	$130,528,600	77.1	12.00	$579,455,700	58.7	53.28	$709,984,300	61.4	65.28
Percent	18.4			81.6			100.0		
Government:									
Amount	$11,933,500	7.0	1.10	$34,348,500	3.5	3.16	$46,282,000	4.0	4.26
Percent	25.8			74.2			100.0		
Total:									
Amount	$169,388,700	100.0	15.57	$986,400,200	100.0	90.70	$1,155,788,900	100.0	106.27
Percent	14.7			85.3			100.0		

TABLE 22.—*Imposts paid by and expenditures made in or for the benefit of residents of all units of government of New York State in 1932*

CLASSIFICATION OF TAXES AND GOVERNMENTAL UNIT LEVYING THEM

Item	State and county			Local government			All governments		
	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
IMPOSTS									
Property:									
Amount	$67,051,500	21.0	$5.33	$840,890,200	94.2	$66.80	$907,941,700	74.9	$72.13
Percent	7.4			92.6			100.0		
[illegible]									
Amount	$81,324,700	25.5	$6.46				$81,324,700	6.7	$6.46
Percent	100.0						100.0		
Other:									
Amount	$171,095,800	53.5	$13.59	$52,209,600	5.8	$4.15	$223,305,400	18.4	$17.74
Percent	76.6			23.4			100.0		
Total:									
Amount	$319,472,000	100.0	$25.38	$893,099,800	100.0	$70.95	$1,212,571,800	100.0	$96.33
Percent	26.3			73.7			100.0		

CLASSIFICATION OF EXPENDITURES BY PURPOSE AND BY GOVERNMENTAL UNIT MAKING THEM

EXPENDED FOR	Total amount	Percent	Per capita	Total amount	Percent	Per capita	Total amount	Percent	Per capita
Highways:									
Amount	$106,378,700	35.8	$8.45	$109,204,500	10.2	$8.68	$215,583,200	15.8	$17.13
Percent	49.3			50.7			100.0		
Education:									
Amount	$12,289,100	4.2	$0.98	$326,737,600	30.7	$25.95	$339,026,700	24.9	$26.93
Percent	3.6			96.4			100.0		
Public benefit									
Amount	$162,627,900	54.8	$12.92	$591,725,800	55.5	$47.01	$754,353,700	55.4	$59.93
Percent	21.6			78.4			100.0		
Government:									
Amount	$15,445,800	5.2	$1.22	$38,206,900	3.6	$3.04	$53,652,700	3.9	$4.26
Percent	28.8			71.2			100.0		
Total:									
Amount	$296,741,500	100.0	$23.57	$1,065,874,800	100.0	$84.68	$1,362,616,300	100.0	$108.25
Percent	21.8			78.2			100.0		

TABLE 23.—*Total debt outstanding in 1932, showing purpose and unit of government by which incurred*

Unit of government by which incurred	Purpose for which originally incurred				Total
	Highway	Education	Public benefit	Government	
State:					
Amount	[illegible]	[illegible]	$225,487,800	$164,843,600	$497,951,200
Percent	20.5	1.1	45.3	33.1	100.0
Per capita	$8.11	$0.44	$17.91	$13.10	$39.56
Counties:					
Amount	$90,000,400	$5,900	$114,427,100	$43,198,800	$247,632,200
Percent	36.3	(¹)	46.2	17.5	100.0
Per capita	$7.15	(²)	$9.09	$3.43	$19.67
Local governments:					
Amount	[illegible]	[illegible]	$1,680,632,800	$347,742,600	$3,030,146,900
Percent	14.4	18.6	55.5	11.5	100.0
Per capita	$34.63	$44.95	$133.51	$27.62	$240.71
Total:					
Amount	[illegible]	[illegible]	$2,020,547,700	$555,785,000	$3,775,730,300
Percent	16.6	15.1	53.5	14.7	100.0
Per capita	$49.89	$45.39	$160.51	$44.15	$299.94

¹ Less than 0.1 percent. ² Less than 1 cent.

The extent of the influence of New York City registrations on the average for the State is readily apparent. The heavy traffic conditions, inaccessibility to through routes, and large proportion of persons unable to finance an automobile account for the relatively low registration in this area. Registration figures possess more significance when expressed in terms of persons per vehicle (table 26). The following relations are apparent: (1) There were more vehicles compared to population in rural than in urban areas; (2) the proportion of trucks registered in rural areas to those in urban places was greater than the proportion of cars in the rural areas to those in the urban areas; (3) the small incorporated communities had relatively more registrations

TABLE 24.—*Liability of residents of rural and urban areas for payment of outstanding debt of State, counties, and local governments in 1932*

Debt liability of residents of	Total debt liability	Percent	Amount per capita
Rural areas	$290,686,000	7.7	$169.79
Places under 2,500	70,638,400	1.9	189.85
Places 2,500 to 14,999	200,808,300	5.3	237.05
Places 15,000 to 74,999	215,964,300	5.7	215.06
Places 75,000 to 399,999	323,937,000	8.6	281.91
Buffalo	160,595,100	4.3	280.23
New York City	2,513,158,300	66.5	362.63
Total	3,775,787,400	100.0	299.95
RECAPITULATION			
Rural areas	290,686,000	7.7	169.79
Urban areas	3,485,101,400	92.3	320.44
Total	3,775,787,400	100.0	299.95

TABLE 25.—*Total debt service payments by all units of government in 1932*

Item	Total amount	Percent	Percentage of total	Amount per capita
Bonded debt				
Interest	$134,430,400	47.5		$10.68
Principal	148,703,900	52.5		11.81
Total	283,134,300	100.0	25.9	22.49
Short-term debt				
Interest	7,218,800	.9		.57
Principal	804,376,700	99.1		63.90
Total	811,595,500	100.0	74.1	64.47
All debt:				
Interest	141,649,200	12.9		11.25
Principal	953,080,600	87.1		75.71
Total	1,094,729,800	100.0	100.0	86.96

TABLE 26.—*Number and types of motor vehicles registered and persons per vehicle in 1932, by place of registration*

Place of registration	Type of vehicles registered				Percent of total	Persons per vehicle		
	Passenger cars	Trucks and busses	Other	Total		Passenger cars	Trucks and busses	Total
	Number	*Number*	*Number*	*Number*	*Percent*			
Rural areas	360, 531	81, 581	6, 334	448, 446	19. 5	4. 7	21. 0	3. 8
Places under 2,500	127, 867	19, 199	1, 632	148, 698	6. 5	2. 9	19. 4	2. 5
Places 2,500 to 14,999	225, 224	34, 810	2, 920	262, 954	11. 4	3. 8	24. 3	[illegible]
Places 15,000 to 74,999	212, 773	31, 571	2, 891	247, 235	10. 8	4. 7	31. 8	4. 1
Places 75,000 to 399,999	232, 915	29, 690	3, 063	265, 668	11. 6	4. 9	38. 7	[illegible]
Buffalo	110, 708	13, 933	1, 320	125, 961	5. 5	5. 2	41. 1	4. 5
New York City	666, 938	121, 234	8, 929	797, 101	34. 7	10. 4	57. 2	8. 7
Total	1, 936, 956	332, 018	27, 089	2, 296, 063	100. 0	6. 5	37. 9	5. 5

RECAPITULATION

Place of registration	Passenger cars	Trucks and busses	Other	Total	Percent of total	Passenger cars	Trucks and busses	Total
Rural areas	360, 531	81, 581	6, 334	448, 446	19. 5	4. 7	21. 0	3. 8
Urban areas	1, 576, 425	250, 437	20, 755	1, 847, 617	80. 5	6. 9	[illegible]	5. 9
Total	1, 936, 956	332, 018	27, 089	2, 296, 063	100. 0	6. 5	37. 9	5. 5
Percentage of total	84. 3	14. 5	1. 2	100. 0				

than any of the other units of government; and (4) exclusive of the incorporated communities under 15,000, the proportionate number of vehicles decreased as the population increased.

MOTOR-VEHICLE IMPOSTS PROVIDED $67 OF EACH $1,000 OF TAXES IN 1932

License fees collected for the 1932 registration year amounted to $37,193,900. Nonresidents obtained licenses for 6,196 vehicles and paid $206,900. New York residents obtained licenses for 2,296,063 vehicles and paid $36,987,000 (table 27). Cars comprised 84.3 percent of the vehicle registrations, and 73 percent of the registration fees were paid for them (fig. 7). This difference is caused by the lower fees paid by passenger vehicles. The contrast between rural and urban areas is interesting. Passenger cars in rural areas constituted 80.4 percent of the rural registrations and 73.2 percent of the rural registration fees were paid for them, while cars in urban places comprised 85.3 percent of the urban registrations and only 72.9 percent of the urban registration fees were paid for them. Passenger cars owned by rural residents comprised 18.6 percent of the total State passenger-car registration and 16.9 percent of the passenger-car registration fees were paid for them. The proportionate difference is even greater for trucks.

HIGHWAY TAXES AND HIGHWAY EXPENDITURES

Expenditures on the State highway system in 1932 were $68,094,300; on the county system, $38,284,400; and on local roads and streets, $109,204,500.

Of the total property taxes expended on all roads and streets, 4.3 percent was expended on State highways; 22.4 percent on county roads; and 73.3 percent on local roads and streets.

Of the total motor-vehicle imposts expended on all roads and streets, 65 percent was expended on the State system, 16.3 percent on county roads, and 18.7 percent on local roads and streets.

Of all taxes and imposts expended on roads and streets, rural property and motor-vehicle owners paid 21.5 percent, and travel by rural owned vehicles made up 18.2 percent of all travel by residents on New York streets and highways; urban property and vehicle owners paid 78.5 percent and urban owned vehicles provided 81.8 percent of the total travel by residents on New York streets and highways.

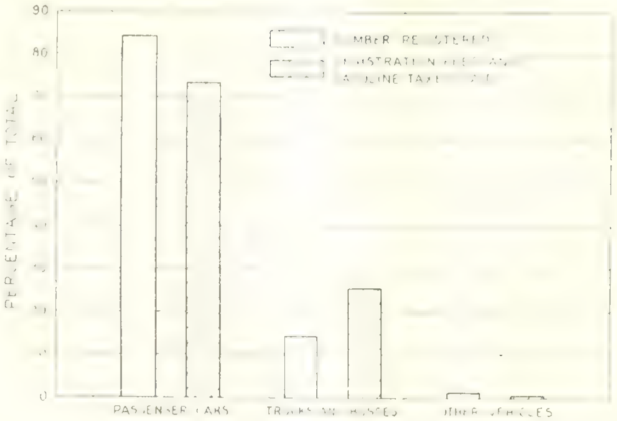

FIGURE 7.—PERCENTAGE DISTRIBUTION OF ALL VEHICLES BY NUMBER REGISTERED AND BY REGISTRATION FEES AND GASOLINE TAXES PAID.

The explanations for these differences are apparent from table 27, which gives the per-vehicle fees. For both cars and trucks in the rural areas lower registration fees were paid than for vehicles in urban places (fig. 8). This was expected because the registration fee schedule is based on the weight of vehicles, and vehicles owned in rural areas tend to be lighter than those owned in urban areas. The heavy contract-hauler and common-carrier trucks are generally registered in the cities or villages. The trucks owned in rural areas, mainly for private use, are light-weight trucks.

The more expensive passenger cars are usually owned by residents of larger cities and villages. The more valuable car is usually also the heavier vehicle. The general tendency for per-vehicle fees to increase as the place of registration becomes larger in population is evident also for trucks as well as for passenger cars.

No motor-fuel tax was collected in New York State until 1929. During the following 4 years the total revenues from this source increased more than 100 percent and the average tax per vehicle doubled. The motor-fuel tax collected in 1932 totaled $40,340,900, of which 74.5 percent was paid for cars and 25.5 percent for trucks and busses. The ratio of the amount contributed by cars to the total amount, for both rural and urban areas, was almost the same.

Residents of rural areas furnished 19.5 percent of the total motor-vehicle registration and paid 15.2 percent of the gasoline tax. The percentages are nearly the same

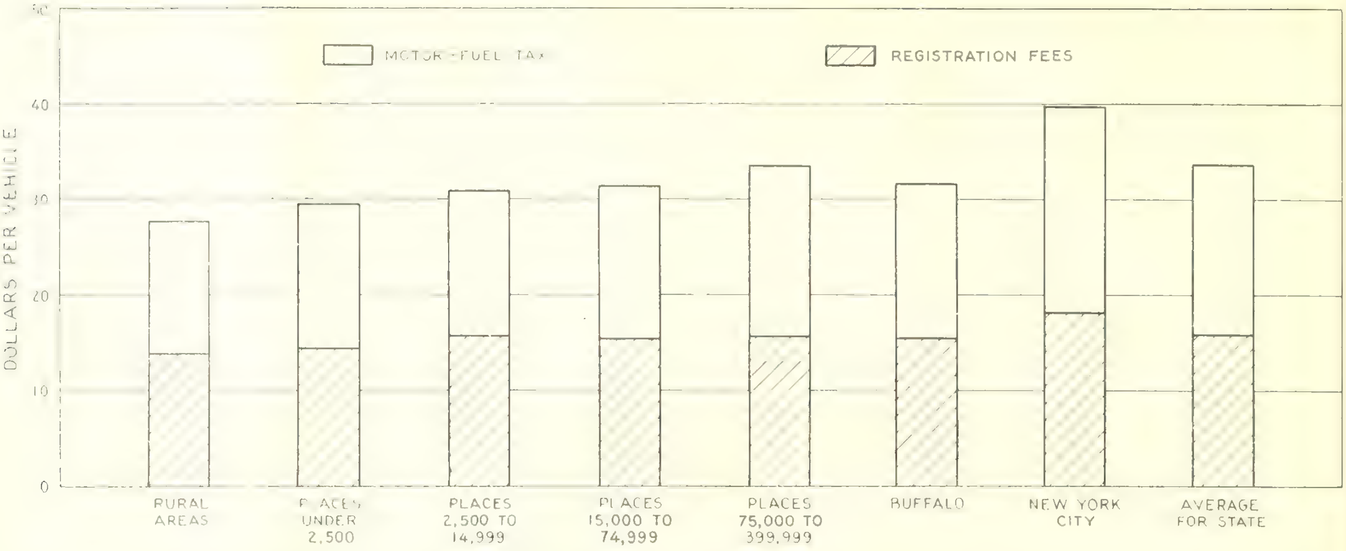

FIGURE 8.—AVERAGE REGISTRATION FEES AND MOTOR-FUEL TAXES PAID BY MOTOR-VEHICLE OWNERS, DISTRIBUTED BY PLACE OF OWNERSHIP.

TABLE 27.—*Motor-vehicle registration fees and motor-fuel taxes paid by vehicle owners in rural and urban areas in 1932*

MOTOR-VEHICLE REGISTRATION FEES

Paid by vehicle owners of—	Total payments				Per-vehicle payments [1]			
	Passenger cars	Trucks and busses	Other	Total	Passenger cars	Trucks and busses	Other	Total
Rural areas	$4,575,200	$1,630,500	$41,000	$6,246,700	$12.69	$19.99	$6.47	$13.93
Urban areas	22,405,800	8,111,700	222,800	30,740,300	14.21	32.39	10.73	16.64
Total	26,981,000	9,742,200	263,800	36,987,000	13.93	29.34	9.74	16.11

MOTOR-FUEL TAX

Paid by vehicle owners of—	Passenger cars	Trucks and busses	Other	Total	Passenger cars	Trucks and busses	Other	Total
Rural areas	$4,725,600	$1,418,600		$6,144,200	$13.11	$17.39		$13.90
Urban areas	25,333,300	8,863,400		34,196,700	16.07	35.39		18.72
Total	30,058,900	10,282,000		40,340,900	15.52	30.97		17.78

REGISTRATION FEES AND MOTOR FUEL TAX

Paid by vehicle owners of—	Passenger cars	Trucks and busses	Other	Total	Passenger cars	Trucks and busses	Other	Total
Rural areas	$9,300,800	$3,049,100	$41,000	$12,390,900	$25.80	$37.38	$6.47	$27.63
Urban areas	47,739,100	16,975,100	222,800	64,937,000	30.28	67.78	10.73	35.15
Total	57,039,900	20,024,200	263,800	77,327,900	29.45	60.31	9.71	33.68

[1] Other vehicles are not included in motor-fuel tax per vehicle, therefore total per-vehicle registration fees and motor fuel taxes do not equal the sum of per-vehicle payments.

for cars and trucks taken separately. For the average car in rural areas a gasoline tax of $13.11 was paid and for the average truck and bus $17.39 was paid. In contrast, urban residents paid $16.07 per car and $35.39 per truck and bus. For the State as a whole for each vehicle registered in 1932 a gasoline tax of $17.78 was paid.

A tendency similar to that observed in the registration fees may also be pointed out for the gasoline tax; i. e., the average tax increased as the size of the place in which the vehicle was registered increased.

Registration fees and gasoline taxes constitute the major portion of the special imposts on motor-vehicle owners. In addition, however, certain miscellaneous fees amounting to $3,996,800 were paid, raising the total contributions by motor-vehicle owners to $81,324,700. The imposts included in this classification were chauffeurs' and operators' licenses, fees from driving school, and other imposts such as fines, penalties, and reregistrations. These taxes averaged less than $2 per vehicle.

Administration of the vehicle and traffic laws and of the motor-fuel tax is performed by the Department of Taxation and Finance. During 1932, $1,497,200 was the cost of administering the vehicle and traffic law, amounting to 65 cents per vehicle registered or 4 percent of the total collections. The greater share of this cost was for the registration and licensing activities. It cost $92,300 to collect the $40,340,900 of gasoline tax, an average of 4 cents per vehicle registered in the State and but 0.2 percent of the total tax collected.

Tables 28, 29, 30, and figure 9 summarize pertinent facts determined by the financial survey. The following statements emphasize some of the most important relations determined by this study.

SUMMARY

1. Rural property owners paid no tax for urban streets.

2. Urban property owners in the villages paid taxes for town highways.

3. Of that portion of the total property tax on rural property expended for highways:

(*a*) 5.7 percent was expended on State trunk highways.
(*b*) 29.4 percent was expended on county roads.
(*c*) 64.9 percent was expended on town highways.

TABLE 28.—*Sources of each $1,000 of taxes in New York in 1932*

Residents of—	Pay in—		
	General property taxes	Motor-vehicle imposts	Miscellaneous imposts
Rural areas	$65.89	$10.73	$19.52
Places under 2,500	14.98	3.69	4.24
Places 2,500-14,999	40.43	7.04	11.6
Places 15,000-74,999	56.16	6.71	11.6
Places 75,000-399,999	76.37	7.65	12.1
Buffalo	37.44	3.55	5.8
New York City	457.50	27.70	119.1
Total	748.77	67.07	184.1

Table 29.—*Percentage distribution of financial, travel, and other data, for 1932*

Class of place	Population	Area	Property valuation	Highway mileages	Motor-vehicles registered	All taxes paid	Motor-vehicle [illegible]	All expenditures	Highway expenditures	Travel performed
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Rural areas	13.6	96.5	10.1	82.7	19.5	13.1	16.0	34.2	52.2	18.2
Places under 2,500	3.0	1.0	3.0	3.3	6.5	3.5	[illegible]	3.1	2.0	7.0
Places 2,500 to 14,999	6.7	.8	6.2	3.7	11.4	7.9	[illegible]	5.8	3.2	11.9
Places 15,000 to 74,999	8.0	.6	6.1	2.4	10.8	7.7	10.0	6.0	2.9	11.3
Places 75,000 to 399,999	9.1	.3	8.0	2.0	11.6	8.7	[illegible]	8.4	4.7	12.4
Buffalo	4.5	.1	3.9	.6	5.5	4.0	[illegible]	3.4	1.0	6.0
New York City	55.1	.7	62.7	5.3	34.7	55.1	41.3	39.1	34.0	33.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
RECAPITULATION										
Rural areas	13.6	96.5	10.1	82.7	19.5	13.1	16.0	34.2	52.2	18.2
Urban areas	86.4	3.5	89.9	17.3	80.5	86.9	84.0	65.8	47.8	81.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Figures for 1930.

Table 30.—*Purposes for which each $1,000 of expenditures were made in New York in 1932*

Expended for	Source of fund expended	Amount
State highways	Taxes paid in:	
	Rural areas	5.30
	Urban areas	23.85
	Federal aid	8.40
	Loans and reserve	12.45
	Total	50.00
County roads	Taxes paid in:	
	Rural areas	7.91
	Urban areas	20.25
	Total	28.16
Local roads and streets	Taxes paid in:	
	Rural areas	16.33
	Urban areas	63.72
	Total	80.05
Total all highways and streets		158.21
Education		248.81
Public benefit		553.61
Government		39.37
Grand total		1,000.00

4. Of that portion of the total tax on urban property expended for highways:

(*a*) 25.7 percent was expended on rural roads.
(*b*) 74.3 percent was expended on urban streets.

5. Of that portion of the total taxes on urban property expended for highways:

(*a*) 3.9 percent was expended on State highways. (The counties contribute funds for the State highway system, and such contributions are financed out of general property taxes and the county portion of motor-vehicle imposts.)

(*b*) 20.2 percent was expended on county roads.

(*c*) 75.9 percent was expended on local roads and streets. The figure of 75.9 percent for local roads and streets may be divided into 1.6 percent of urban funds which went to town highways and 74.3 percent to city and village streets. The figure of 1.6 percent was the contribution by village taxpayers to town highways.

6. Since, of the total property valuation of $35,101,205,600, $3,558,877,300 or 10.1 percent was in rural areas and 89.9 percent was in urban areas:

(*a*) Expenditures from property taxes for all highways were at the following rates:

Rural—88.5 cents per $100 of full valuation.
Urban—31.5 cents per $100 of full valuation.

(*b*) Expenditures from property taxes for the State highways were at the following rates:

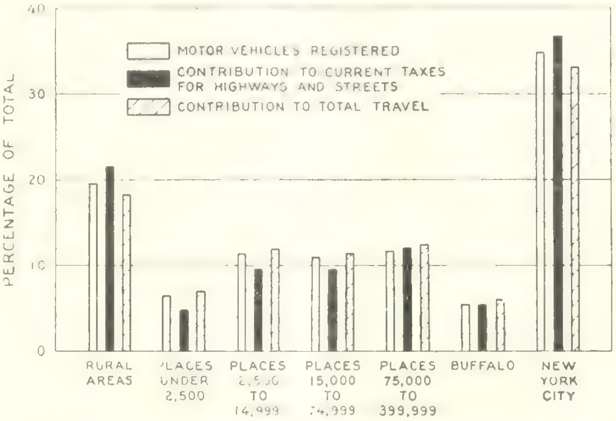

Figure 9.—Percentage Distribution of Motor Vehicles Registered, Contribution to Current Taxes Expended on Highways and Streets, and Travel Performed, Distributed by the Several Classes of Places.

Rural—5 cents per $100 of full valuation.
Urban—1.2 cents per $100 of full valuation.

(*c*) Expenditures from property taxes for county roads were at the following rates:

Rural—26.1 cents per $100 of full valuation.
Urban—6.4 cents per $100 of full valuation.

(*d*) Expenditures from property taxes for town highways and city and village streets were at the following rates:

Rural—57.4 cents (all for town highways) per $100 of full valuation.
Urban—23.9 cents per $100 of full valuation.

7. Of that portion of the total property taxes used for all highways:

(*a*) 4.3 percent was expended on State highways.
(*b*) 22.4 percent was expended on the county roads.
(*c*) 15.6 percent was expended on the town highways.
(*d*) 57.7 percent was expended on city and village streets.

8. Of the total motor-vehicle imposts expended on all classes of roads and streets:

(*a*) Rural motor-vehicle owners paid 16 percent and travel by these same rural owners made up 18.2 percent of the total travel on all classes of roads and streets.

(*b*) Urban motor-vehicle owners paid 84 percent and accounted for 81.8 percent of the total travel.

9. Of the total motor-vehicle imposts:

(*a*) 65 percent was expended on the State highways.
(*b*) 16.3 percent was expended on county roads.
(*c*) 3 percent was expended on town highways.
(*d*) 15.7 percent was expended on city and village streets.

10. Of all imposts and taxes expended on all highways and streets:

(*a*) 21.2 percent was expended on State highways.
(*b*) 20.5 percent was expended on county roads.
(*c*) 11.9 percent was expended on town highways.
(*d*) 46.4 percent was expended on city and village streets.

11. Of that portion of the total of all taxes and imposts which was expended on all highways and streets:

(*a*) Rural property and motor-vehicle owners paid 21.5 percent, and travel by rural vehicles made up 18.2 percent of all New York travel on all New York streets and highways.

(*b*) Urban property and vehicle owners paid 78.5 percent while urban vehicles provided 81.8 percent of the total travel by residents on all New York streets and highways.

12. Receipts from motor-vehicle imposts, if they had been used solely by the State for highway purposes in 1932, would have been more than adequate to pay for all of the expenditures on the State highway system including the cost of grade crossing eliminations.

13. The State's portion of the motor-vehicle imposts if used solely for highways (approximately 75 percent) plus Federal-aid allotments, also would have been more than adequate to pay for the expenses of the State highway system.

14. In 1932, 8.3 percent of the total expenditures on the State highway system was financed out of county funds as occasioned by snow removal performed, right of way purchased, and maintenance performed by the county on State highways.

15. The counties received $16,710,800 as their portion of the motor-vehicle imposts and expended $5,632,700 of their funds for State highway purposes.

16. The expenditures for State highways by the State constituted 33.5 percent of the total expenditures by the State, and the total expenditures by the State on the State highways constituted 29 percent of all highway expenditures in the State and 4.6 percent of all expenditures for all purposes by all units of government in 1932.

17. For the average truck in New York an excess of $30.86 was paid in motor-vehicle registration fees and motor-fuel taxes over similar taxes paid for the average car. Owners of the 332,018 trucks thus paid $10,246,100 more than was paid for the same number of cars. This amount is almost 75 percent of the total State expenditures for the maintenance of State highways in 1932.

18. Local governments—towns, special districts, cities, and villages—are the principal units of government in New York considered on the basis of the amount of expenditures made in the State in 1932 (78.2 percent of total for all units of government), the amount of taxes levied (73.7 percent), and the debt incurred (80.2 percent).

19. Measured by expenditures, public benefit functions in New York were by far the most extensive activities, constituting 55.4 percent of all expenditures for all purposes and exceeding by 30.5 percent the costs of education and by 39.6 percent the highway expenses.

20. Of each $1,000 of taxes, $748.77 was paid in general property taxes, $67.07 in motor-vehicle imposts, and $184.16 in other imposts.

PUBLIC ROADS TO BE PUBLISHED IN SPANISH

"Carreteras", a Spanish translation of Public Roads is soon to be published in Argentina and will be available for circulation in Spanish-speaking countries. A few months ago Ing. J. Allende Posse, head of the national highway organization of Argentina, while inspecting road construction in the United States, expressed a desire to keep the highway engineers of Argentina informed regarding research and methods of construction in this country. Difference in language has been a serious difficulty which he proposed to overcome by publishing Public Roads in Spanish. Arrangements have been completed and the first issue of "Carreteras", which will contain the report that appeared in the March 1936 issue of Public Roads, will be published in the near future.

A nominal charge will be made for "Carreteras", and subscriptions should be placed with the Jefe De Publicidad, Direccion Nacional de Vialidad, Buenos Aires, Argentina.

SECOND CONGRESS OF THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS TO BE HELD IN LONDON, APRIL 19-24, 1937

For those concerned with concrete, natural stones, and ceramic materials the congress of the International Association for Testing Materials, which is to be held in London next April will be of considerable interest. The subjects to be discussed are divided into four groups: Metals, inorganic materials, organic materials, and subjects of general importance. The second group, which covers concrete, natural stones, and ceramic materials, has Prof. E. Suenson, of Denmark, as president, and an inspection of the preliminary list of papers which are to be presented indicates that the treatment of the different subjects will be most comprehensive, as the papers originate in some 11 different countries. Among the subjects included under "Concrete" are the testing of aluminous cement and plastic mortars, the development of heat by cement, sea-water cements, waterproofing compounds, the creep of concrete under load, vibrated concrete, cement pipes, and the strength of reinforced concrete beams. Natural stones are discussed in Austrian, German, and British papers, while under ceramic materials, the general testing of ceramic materials, the strength and testing of bricks and tiles, refractories, electrical porcelain, and the classification of clays are dealt with.

The last congress for testing materials was held in 1931, and the association says that every effort is being made to insure that the knowledge in this most important field will be brought completely up to date. The papers will be presented in the form of summaries, so that a large amount of information will be made available in easily accessible form. Inquiries should be addressed to the honorary secretary of the congress, Mr. K. Headlam-Morley, at the offices of the British committee, the International Association for Testing Materials, 28 Victoria Street, London, S. W. 1.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936-1937

AS OF OCTOBER 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAIL-ABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$5,208,287				$585,592	$292,796	23.2	$474,000	$237,000	13.7	$4,678,491
Arizona	3,564,709	$1,794,231	$1,385,866	98.3	744,298	615,810	21.7	351,723	266,033	18.3	1,296,951
Arkansas	4,275,929							1,070,297	1,069,785	30.0	3,206,144
California	9,508,671	2,717,634	1,570,947	69.0	9,467,091	5,422,502	259.7	2,709,024	1,560,909	55.8	954,313
Colorado	4,575,144	2,175,545	1,216,773	93.4	3,324,311	1,746,114	109.9	1,884,899	1,052,147	72.2	560,111
Connecticut	1,582,913	282,616	141,308	4.8	813,140	406,867	10.3	122,827	61,414	1.4	973,324
Delaware	1,218,750	239,537	119,768	30.3	340,946	170,375	9.9	402,095	194,327	13.0	734,280
Florida	3,315,558	831,120	415,560	27.5	622,727	311,363	19.3	13,828	6,914		2,581,721
Georgia	6,336,443	825,838	405,625	62.4	2,282,251	1,116,507	136.3	854,393	418,082	36.5	4,396,229
Idaho	3,065,304	1,642,180	975,613	201.1	1,522,870	911,284	87.9	689,563	412,629	42.5	765,778
Illinois	10,325,922	3,447,530	1,720,251	72.0	8,101,079	4,016,065	125.1	3,553,230	1,751,190	88.5	2,838,416
Indiana	6,184,258	3,517,770	1,755,240	109.2	2,653,849	1,326,216	96.1	4,1[illegible],246	2,093,824	103.3	1,008,978
Iowa	6,466,628	5,055,011	2,386,054	388.3	3,992,495	1,923,329	151.6	2,0[illegible],936	1,009,653	68.0	1,147,592
Kansas	6,631,085	2,082,561	1,040,612	409.2	4,449,151	2,198,122	486.4	3,064,313	1,532,090	160.2	1,860,261
Kentucky	4,611,955	2,140,374	1,049,101	139.5	406,528	203,264	14.2	1,238,575	614,842	45.9	2,744,749
Louisiana	3,557,930	1,458,617	729,308	52.9	1,143,103	571,537	38.3	655,364	327,682	16.1	1,929,403
Maine	2,177,197	1,643,303	820,854	48.5	721,452	360,726	21.3	715,448	357,724	14.5	637,893
Maryland	2,050,870				791,731	395,831	11.3	937,600	428,277	12.5	1,226,761
Massachusetts	3,485,364				3,788,933	1,844,467	12.2	1,063,134	531,567	8.5	1,109,331
Michigan	7,668,768	4,082,735	2,037,670	162.4	9,759,918	4,879,434	289.0	1,270,694	635,347	33.6	116,317
Minnesota	6,849,307	7,409,615	3,441,390	472.2	1,971,297	976,460	113.3	1,996,284	998,142	85.3	1,433,315
Mississippi	4,387,636				108,905	54,452	8.1	1,334,523	667,211	79.2	3,665,972
Missouri	7,601,200	2,645,970	1,318,736	364.7	6,447,469	3,222,914	264.7	2,810,227	1,373,248	141.7	1,686,302
Montana	5,122,333	3,649,930	2,043,463	375.7	2,113,657	1,183,437	145.4	1,502,528	803,073	64.4	1,092,360
Nebraska	5,167,930	1,334,766	667,304	106.7	3,552,893	1,782,029	320.7	577,816	288,908	26.3	2,429,689
Nevada	3,189,479	1,342,745	1,157,803	253.7	718,126	620,562	29.4	83,313	72,545	1.1	1,338,468
New Hampshire	1,218,750	734,176	360,712	22.2	179,821	89,585	3.0	196,960	98,317	1.9	670,136
New Jersey	3,352,469	565,970	282,965	12.0	3,642,660	1,734,799	37.0	324,309	162,154	5.4	1,172,550
New Mexico	3,990,023	2,298,579	1,396,900	173.6	1,940,171	1,195,049	160.0	1,265,576	769,714	90.8	628,361
New York	12,306,710	3,669,155	1,816,735	83.0	14,772,034	7,272,967	271.4	2,297,700	1,148,850	26.9	2,068,158
North Carolina	5,879,466	1,500,282	749,559	199.6	2,915,535	1,456,870	291.5	971,681	435,809	43.4	3,237,228
North Dakota	3,918,269				191,740	101,206	.1	208,710	111,743	.3	3,705,319
Ohio	9,131,204	761,780	380,890	12.3	6,443,773	3,105,588	80.7	1,616,442	724,528	11.1	4,920,198
Oklahoma	5,884,927	1,687,839	882,204	60.8	1,817,027	952,592	62.3	1,517,374	741,361	57.2	3,308,770
Oregon	4,089,711	2,197,702	1,324,878	89.5	2,880,855	1,701,591	93.5	967,166	562,452	40.1	500,789
Pennsylvania	10,695,448	4,272,818	2,136,140	73.4	7,778,840	3,881,486	105.8	3,528,590	1,752,706	50.9	2,925,116
Rhode Island	1,218,750				386,963	193,482	5.1	551,309	275,655	4.1	749,614
South Carolina	3,381,337	32,682	15,000	8.7	2,622,757	1,064,493	198.9	1,912,952	804,277	135.2	1,497,567
South Dakota	4,078,647	1,194,361	673,302	157.5	237,222	140,852	35.5	275,011	150,780	20.3	3,113,713
Tennessee	5,268,270	1,792,087	895,471	75.2	909,406	454,593	34.0	209,297	104,648	9.0	3,813,458
Texas	15,548,821	8,141,882	4,062,393	462.4	6,481,241	3,234,685	320.7	695,574	347,173	18.8	7,904,569
Utah	2,826,960	1,781,746	1,276,399	125.6	626,138	450,940	37.4	336,078	213,280	16.3	886,341
Vermont	1,218,750	1,197,797	596,273	59.4	718,663	348,488	20.0	280,100	122,435	6.0	151,554
Virginia	4,559,200	1,291,878	643,584	51.2	2,785,398	1,392,696	116.0	1,999,359	999,676	61.0	1,523,244
Washington	3,904,738	2,976,479	1,567,003	93.3	2,555,685	1,342,471	132.9	516,534	271,400	8.9	723,864
West Virginia	2,716,754	208,599	104,300	9.7	1,279,426	639,694	45.9	841,850	420,925	20.3	1,551,836
Wisconsin	6,090,504	2,851,076	1,378,890	106.7	4,596,563	2,262,758	177.8	649,950	320,345	23.9	2,128,511
Wyoming	3,121,972	2,594,867	1,582,302	305.0	1,283,686	785,173	190.8	34,226	21,790	1.0	732,707
District of Columbia											
Hawaii	1,218,750				467,855	231,167	8.2	69,938	34,754	1.6	952,829
TOTALS	243,750,000	92,071,383	48,525,146	5,722.9	138,042,271	70,586,288	5,233.9	56,922,171	29,359,885	1,887.6	95,278,681

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF OCTOBER 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 954,131	$ 954,131	51.1	$ 3,035,965	$ 3,035,965	77.9	$ 68,086	$ 68,086	8.7	$ 92,932
Arizona	2,569,841	2,091,221	1,900,872	132.9	926,779	589,840	54.6	22,200	22,200	1.6	56,929
Arkansas	3,352,061	2,004,968	1,989,135	186.4	1,242,977	1,239,356	159.0	46,803	46,523	2.7	77,046
California	7,747,928	4,426,917	4,259,564	188.2	3,366,229	3,331,255	65.9	73,063	73,063	1.2	84,046
Colorado	3,395,263	1,392,374	1,390,897	76.5	731,519	731,518	27.6				1,272,849
Connecticut	1,418,709	90,507	89,377	.2	545,855	524,898	5.9	328,018	328,018	9.1	476,416
Delaware	900,310	170,776	168,080	29.2	443,540	414,700	19.9	250,398	171,583	17.7	145,946
Florida	2,597,144	638,166	638,166	27.6	1,704,848	1,704,848	59.8	212,677	212,677	11.6	41,453
Georgia	4,988,967	439,351	438,662	29.0	484,328	484,328	34.5	647,444	647,444	41.7	3,418,533
Idaho	2,222,747	1,436,000	1,418,429	120.3	808,409	771,953	62.9				32,365
Illinois	8,694,009	5,518,233	5,514,724	328.6	2,885,005	2,880,305	122.4	283,526	283,526	20.2	15,454
Indiana	4,941,255	883,857	880,554	38.0	4,180,838	3,960,933	190.5	37,924	37,924	6.3	61,843
Iowa	4,991,664	1,670,780	1,594,689	264.7	3,498,499	3,340,569	239.4	49,826	49,050	8.5	7,356
Kansas	4,994,975	1,720,535	1,720,291	194.5	3,279,778	3,269,967	180.6	4,717	4,717		
Kentucky	3,726,271	1,528,096	1,520,582	197.9	1,389,464	1,389,464	125.0	573,566	573,558	26.5	242,667
Louisiana	2,890,429	628,845	493,243	32.4	2,105,535	1,902,329	119.8	402,579	337,600	22.4	152,257
Maine	1,676,799	1,081,242	1,080,012	45.7	498,618	498,618	24.6	52,100	52,100	1.7	46,069
Maryland	1,750,738	122,867	122,867	7.4	569,657	529,787	10.9	783,659	660,188	23.3	437,896
Massachusetts	3,262,885	50,481	50,481	.6	1,867,213	1,867,213	12.3	337,664	337,664	5.0	1,007,526
Michigan	6,301,414	4,664,500	4,604,470	208.0	1,499,021	1,499,021	76.8	55,700	55,700	4.6	142,223
Minnesota	5,277,145	4,013,661	3,435,080	676.6	2,155,773	1,636,739	224.0	281,464	188,074	9.4	17,252
Mississippi	3,457,552	901,439	900,469	83.1	2,128,679	2,124,212	117.0	159,490	159,490	15.8	273,380
Missouri	6,012,652	3,087,860	3,066,506	668.2	2,451,252	2,345,978	106.4	700,306	532,289	3.1	67,879
Montana	3,676,416	3,093,066	3,093,066	174.0	514,971	514,971	11.3	39,585	31,615	10.0	36,764
Nebraska	3,870,739	1,399,755	1,379,246	153.5	2,151,471	2,125,666	204.2	118,088	118,088	12.2	247,739
Nevada	2,243,074	1,521,413	1,475,055	66.5	485,320	485,320	24.7	2,738	2,738	.3	279,961
New Hampshire	945,225	353,695	350,039	19.4	398,849	376,750	13.2	48,230	48,230	.3	170,206
New Jersey	3,129,805	93,993	93,993	2.2	2,487,986	2,471,831	26.1	508,731	499,762	5.5	64,220
New Mexico	2,871,397	1,777,970	1,777,267	147.0	587,069	587,069	32.6	438,125	438,125	19.1	68,937
New York	11,046,377	4,337,273	4,264,082	83.9	6,790,600	6,450,029	84.0	328,700	328,700	2.5	3,566
North Carolina	4,720,173	900,349	900,349	60.9	3,066,460	3,053,871	204.3	669,686	576,813	21.7	189,140
North Dakota	2,867,245	789,824	789,287	129.5	1,723,545	1,720,520	162.8	225,493	225,493	32.0	131,945
Ohio	7,670,815	1,531,552	1,519,652	45.8	4,560,171	4,426,443	143.6	987,845	958,640	85.6	766,079
Oklahoma	4,580,670	949,097	940,883	82.7	2,426,515	2,423,887	238.1	774,401	767,273	60.0	448,628
Oregon	3,038,642	1,625,881	1,621,006	141.2	1,541,402	1,176,860	15.2	109,669	107,719	10.4	133,057
Pennsylvania	9,347,797	1,196,870	1,135,212	63.0	1,829,646	1,825,608	50.6	1,945,378	1,907,740	68.1	4,479,237
Rhode Island	989,208	682,694	681,082	11.9	298,453	298,453	6.9				9,673
South Carolina	2,702,012	682,189	649,539	74.6	1,497,560	1,441,830	132.8	270,906	266,452	21.1	344,192
South Dakota	2,976,454	1,441,331	1,441,331	315.6	1,084,918	1,084,918	127.0	271,618	271,618	29.0	178,587
Tennessee	4,192,460	1,434,869	1,432,490	66.3	1,417,563	1,417,563	46.2	452,468	452,468	22.8	889,940
Texas	11,989,350	8,682,940	7,886,409	794.7	4,362,446	3,973,228	317.2	76,061	60,475	6.0	64,238
Utah	2,067,154	1,244,273	1,116,701	142.6	778,767	746,853	45.4	33,660	33,660	2.1	169,940
Vermont	924,306	642,881	564,011	16.1	380,536	317,938	5.7	7,880	7,770		34,587
Virginia	3,652,667	2,210,531	2,140,006	719.9	1,066,484	1,060,747	279.7	296,779	295,720	41.3	156,194
Washington	3,026,161	2,385,763	2,168,811	149.4	900,911	742,570	14.1	92,098	92,098	1.2	22,683
West Virginia	2,231,412	194,382	194,382	11.8	1,762,939	1,759,386	65.5	163,409	162,677	12.9	114,967
Wisconsin	4,823,884	3,473,308	3,098,486	247.5	2,029,303	1,720,935	93.2	3,355	3,355	2.9	1,108
Wyoming	2,219,155	1,135,864	1,135,849	96.6	1,003,194	1,003,188	43.4	60,800	41,934	.1	38,184
District of Columbia	949,496	909,101	909,101	8.5	25,011	4,295	.2	25,600	362	.2	35,738
Hawaii	926,033	142,719	129,996	2.6	502,444	494,109	6.3	54,421	53,884	1.5	248,044
TOTALS	195,000,000	84,350,390	81,123,612	7,414.8	87,494,315	83,783,634	4,512.0	13,376,934	12,594,883	709.9	17,497,871

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF OCTOBER 31, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	
Alabama	$4,034,617	$440,449	$440,449	7		4	$2,984,188	$2,984,188	30			$474,535	$474,535	4		8	$135,445
Arizona	1,256,099	398,678	394,444	5			723,342	711,898	7			63,200	63,200	1			86,558
Arkansas	3,574,060	1,082,359	1,078,173	26	3		1,784,681	1,781,558	25	2		662,597	661,542	8	1	29	52,788
California	7,486,362	2,637,534	2,531,037	17	6		4,776,686	4,638,899	34	2							316,426
Colorado	2,631,567	926,063	905,063	18			639,929	639,929	6	1		380,629	380,600	3			705,975
Connecticut	1,712,684						563,087	491,009	3	1	1	494,014	494,014	1	2		727,661
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	660,331	658,600	5	4		1,334,594	1,334,014	15	2		396,932	396,932	9			438,337
Georgia	4,895,949	12,090	12,090	1			318,336	318,336	5	2		546,193	546,193	17			4,019,330
Idaho	1,674,479	800,908	800,908	12	1		315,924	315,924	5			153,291	153,291	1		18	404,355
Illinois	10,307,184	1,193,414	1,193,414	16			6,452,415	6,452,415	39	3		1,507,983	1,507,983	9	2		1,153,372
Indiana	5,111,096	241,288	241,288	4			4,629,802	4,506,683	33	11		405,820	354,820			162	8,306
Iowa	5,600,679	835,749	802,534	25	2		4,167,065	4,117,883	73	7		610,765	599,350	9		8	80,912
Kansas	5,246,258	595,723	595,723	8			4,577,171	4,521,743	44	1		128,792	128,792	3		3	
Kentucky	3,672,387	111,700	111,700	4			2,561,827	2,272,095	18	2		156,898	156,898	1	2		1,131,694
Louisiana	3,213,467						1,447,148	1,447,148	13	1		967,081	922,616	8	3		843,703
Maine	1,426,861	385,978	385,645	11			700,536	699,945	9			81,675	81,675	1		2	259,596
Maryland	2,061,751						477,688	469,649	4	2		1,064,147	1,041,679	4	2	19	550,423
Massachusetts	4,210,833	117,449	117,449	2			1,977,105	1,977,105	15	2		1,034,152	1,034,152	5	2		1,082,128
Michigan	6,765,197	1,492,775	1,492,775	19	4		5,056,377	5,011,877	24	3		237,120	237,120		1		23,425
Minnesota	5,395,441	1,460,138	1,459,792	43	4	36	3,679,391	3,484,020	43	5	5	145,800	145,800		2	1	305,828
Mississippi	3,241,475	171,046	171,046	8	1		2,333,513	2,333,513	41	2	1	83,000	83,000	5		3	653,916
Missouri	6,142,153	261,639	261,639	5			5,580,301	5,479,026	40			367,252	253,300	1		2	148,187
Montana	2,722,327	2,010,499	2,010,499	30	6		649,819	649,819	7								62,009
Nebraska	3,556,441	1,051,080	1,051,080	43			1,973,990	1,973,990	33	1	5	434,876	434,876	4	1	18	96,496
Nevada	887,260	306,096	306,096	7			599,335	577,534	3	1		3,630	3,630			5	
New Hampshire	822,484	151,745	151,745	1	2		350,493	350,493	6	2	1						320,246
New Jersey	3,983,826	59,838	59,838		1		1,836,798	1,825,753	14	1		708,283	708,283	3	1		1,389,953
New Mexico	1,725,286	532,909	532,909	10			925,812	925,812	6	1		72,214	72,214	1			194,352
New York	13,577,189	637,207	637,207	2	3		9,910,837	9,649,991	31	33		1,467,700	1,467,700	7	5		1,822,291
North Carolina	4,823,958	476,941	476,941	7	5		2,009,985	2,009,985	25	8		1,114,596	1,099,096	11	5	61	1,237,936
North Dakota	3,207,473	210,034	210,034	5			1,824,361	1,823,361	36	1		217,540	217,540	4	3		956,537
Ohio	8,439,897						3,677,330	3,464,031	24	2		2,942,293	2,793,989	15	3		2,181,877
Oklahoma	5,004,711	1,208,387	1,208,387	26	1		1,680,402	1,680,402	18	2		568,379	568,379	7	3		1,547,543
Oregon	2,334,204	335,153	335,153	4	3		2,071,153	1,943,537	12	3		41,500	41,500	1		2	14,013
Pennsylvania	11,483,613	390,192	338,959	17			5,673,422	5,163,635	35	15		2,745,070	2,703,208	13	1		3,277,810
Rhode Island	699,691	236,879	236,879		1		418,195	417,129	4			21,195	21,195		1		24,488
South Carolina	3,059,956	273,675	270,371	9		3	1,539,890	1,524,538	28	7		259,614	259,489	1	1	50	1,005,558
South Dakota	3,249,086	435,409	435,409	17			1,633,542	1,633,542	34	3	11	291,116	291,116	5		19	889,019
Tennessee	3,903,979	254,476	254,476	7		4	1,142,547	1,142,547	14	2	2	673,662	673,662	9	1	16	1,833,294
Texas	10,855,982	1,942,453	1,942,453	34	6		7,347,903	7,341,526	83	8		1,264,951	1,211,992	7	1	167	360,010
Utah	1,230,763	87,218	85,829	1	1		1,015,391	998,743	12			93,695	93,695	2			52,496
Vermont	729,857	462,107	458,624	7	5		172,547	157,272	1	1	4	75,853	44,324	2		9	69,638
Virginia	3,774,287	532,655	532,655	19	1		1,484,508	1,374,642	19	5		662,182	662,178	14	3	12	1,204,812
Washington	3,095,041	691,778	686,978	12	3	5	2,141,128	2,140,703	10	8		4,290	4,290			2	263,070
West Virginia	2,677,937						1,211,697	1,211,673	11	2		495,561	495,561	10	1	4	970,703
Wisconsin	5,022,683	793,936	793,936	12	1		3,653,409	3,588,328	24	5							640,418
Wyoming	1,360,841	251,237	251,131	4			798,106	798,101	7			65,000	30,000	1			281,609
Dist. of Columbia	410,804						425,564	396,804	3								14,000
Hawaii	453,703						522,380	453,703	5								
TOTALS	196,000,000	27,157,215	26,921,358	510	64	52	113,915,136	111,326,451	1032	160	30	24,185,076	23,615,409	207	47	620	34,136,782

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SEPARATE REPRINT FROM THE YEARBOOK

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TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF OCTOBER 31, 1936

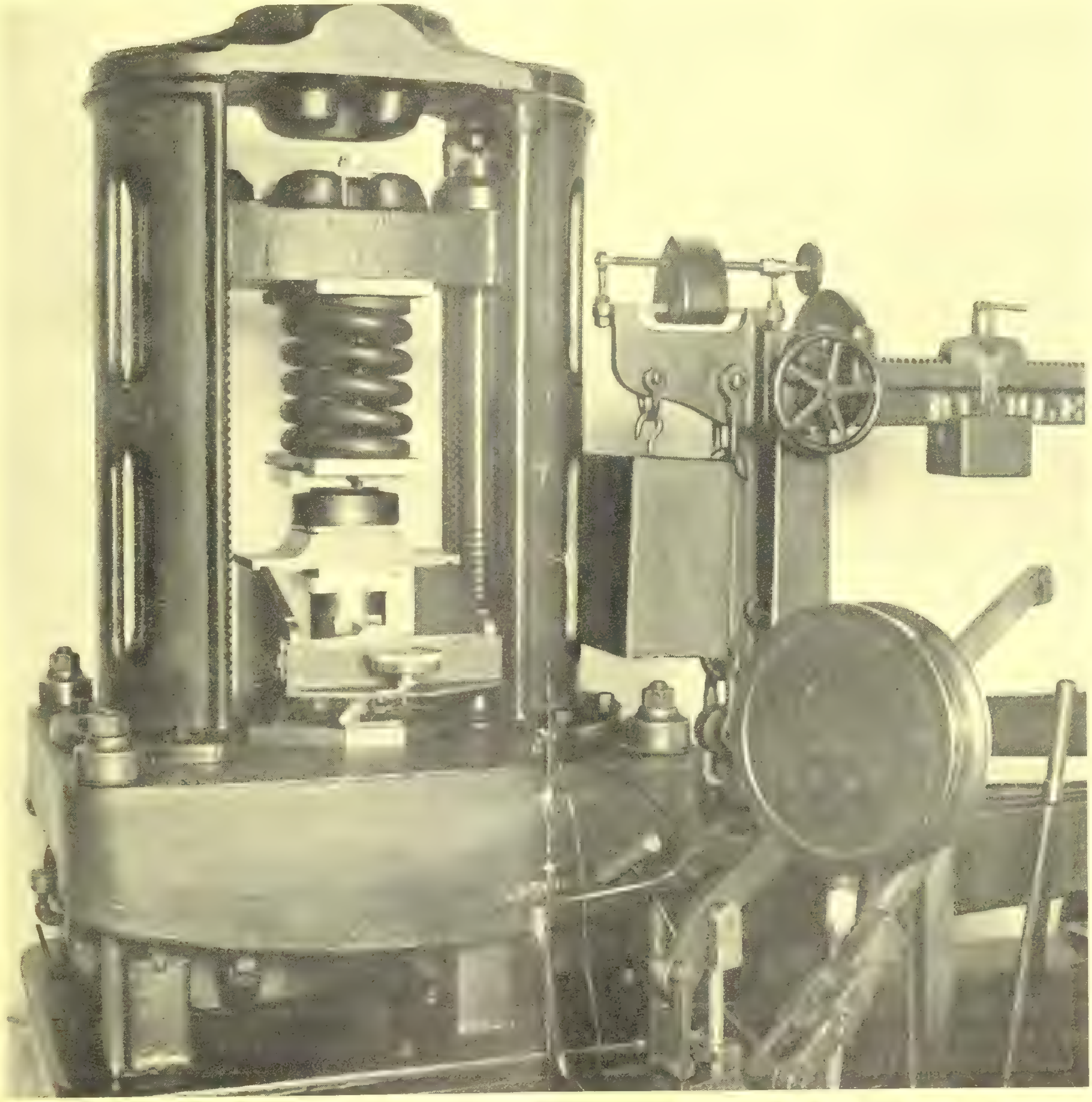
STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$15,365,075	$ 8,304,382	$3,512,878	753.3	$ 467,758	$ 52,665	$ 415,093	16.7		$ 304,982	2.5	$ 13,085	$ 26,890
Arizona	5,211,960	2,641,935	8,320,818	5,204,513	2,570,184	543.0	12,500		12,500					7,447	59,250
Arkansas	6,748,335	3,428,049	10,406,509	6,634,351	3,303,237	618.5	128,046	39,554	88,261	3.7	$ 26,258	18,148	1.0	48,172	18,403
California	15,607,354	7,932,206	30,537,308	15,586,149	7,774,590	758.8	115,026		115,016			820		21,205	41,781
Colorado	6,874,530	3,486,006	11,255,101	6,871,470	3,441,557	639.7						6,619	1.3	2,560	37,530
Connecticut	2,865,740	1,454,368	4,514,547	2,756,269	1,312,944	74.0	36,318	36,318			22,245			48,909	141,924
Delaware	1,319,028	669,345	2,580,744	1,818,804	815,188	128.3	109,467		105,525	1.6				284	2,682
Florida	5,231,434	2,651,343	8,337,748	5,175,534	2,344,564	305.6	254,979		230,665	4.0	56,300	67,339	.5		18,775
Georgia	10,081,185	5,113,491	12,446,454	9,323,487	2,901,276	734.0	1,338,135	403,675	934,433	91.7	84,072	166,158	3.6	279,952	1,111,025
Idaho	4,490,149	2,277,456	6,927,035	4,416,568	2,088,070	501.1	157,743		155,185	.4	42,905	1,521		26,776	32,710
Illinois	17,570,770	8,921,401	25,063,825	16,535,536	7,260,243	695.1	2,446,315	635,560	1,527,395	21.9	60,380	7,424	20.0	39,294	26,339
Indiana	10,037,343	5,088,963	15,312,360	9,555,563	4,723,209	475.6	364,807	158,875	205,932	11.5		108,068		12,405	51,754
Iowa	10,093,960	5,118,351	15,428,981	10,055,161	4,777,361	1,221.9	361,891		341,000	5.4	499				
Kansas	10,094,604	5,117,575	15,350,281	10,003,733	5,012,125	1,131.1	228,634	79,764	61,887	14.4				6,107	43,663
Kentucky	7,517,359	3,818,311	11,944,166	7,448,139	3,554,163	867.7	218,152	59,003	159,149	5.2		72,331	2.8	10,217	32,669
Louisiana	5,828,591	2,963,932	8,983,157	5,731,324	2,593,089	252.5	318,465	56,549	198,434	13.4		128,372	5.2	40,718	44,037
Maine	3,369,917	1,711,586	5,239,639	3,346,881	1,657,506	193.1	7,234		7,234		16,120	11,800	.9	6,916	35,046
Maryland	3,564,527	1,810,058	5,304,565	3,345,772	982,038	143.7	270,868	131,266	127,806	9.8		347,837	7.6	87,489	352,376
Massachusetts	6,597,100	3,350,474	9,852,801	6,552,733	2,647,991	115.2	431,715		431,715	.3		91,944	.1	44,367	178,824
Michigan	12,736,227	6,452,508	20,358,539	12,696,114	6,060,606	754.9	413,100	40,113	252,523	13.2		136,788	.4		2,651
Minnesota	10,656,569	5,425,551	16,086,304	10,520,596	4,749,113	1,632.0	494,238	58,110	390,348	17.2		34,800	.6	77,863	251,290
Mississippi	6,976,675	3,540,227	12,548,013	6,723,551	2,863,665	715.1	787,650	188,861	598,789	28.8	3,960	41,111	1.9	62,304	36,662
Missouri	12,180,306	6,173,740	17,409,640	11,637,146	4,718,947	1,436.5	2,114,082	471,210	1,380,892	15.3		62,100		71,949	11,801
Montana	7,439,748	3,769,734	11,707,589	7,423,766	3,610,494	1,048.2	147,241		147,241	10.2				15,982	11,999
Nebraska	7,826,961	3,964,304	12,833,314	7,813,593	3,613,893	1,018.3	283,045		270,939	27.8		63,537	5.9	15,368	15,995
Nevada	4,545,917	2,302,356	7,078,791	4,545,917	2,266,933	764.5	26,804		26,804			1,650			6,969
New Hampshire	1,909,339	969,462	2,981,515	1,904,951	933,904	77.7	4,174		4,174			16,591	.6	4,888	14,793
New Jersey	6,345,039	3,220,879	8,075,122	6,050,468	1,519,036	82.0	2,148,474	120,518	1,499,346	14.2	82,145		.6	92,907	202,497
New Mexico	5,792,935	2,941,700	8,316,508	5,776,859	2,819,242	743.9	32,518		20,225	1.5				16,076	102,233
New York	22,330,101	11,327,921	38,706,319	21,769,967	10,046,563	815.2	1,815,030	414,610	1,031,299	8.6	111,647	162,275	1.3	33,877	87,783
North Carolina	9,522,293	4,840,941	14,668,317	9,048,673	4,394,008	1,329.6	540,290	402,234	138,056	27.7	51,017	253,514	8.2	20,369	55,363
North Dakota	5,804,448	2,938,967	8,283,425	5,589,998	1,968,494	2,092.9	570,401	139,342	409,600	50.7	15,703	219,659	27.9	59,405	341,214
Ohio	15,434,592	7,805,012	23,905,703	15,324,142	6,775,436	774.3	1,121,223	104,228	969,176	21.9	34,023	81,694	4.3	22,200	38,706
Oklahoma	9,216,798	4,685,180	14,528,221	9,146,846	4,303,265	804.9	182,756	67,007	115,745	1.6		174,301	.2	2,945	91,868
Oregon	6,108,846	3,097,814	9,772,555	5,985,422	2,932,035	465.4	221,747	64,950	89,384	3.3		25,041		56,524	51,354
Pennsylvania	18,891,004	9,590,788	28,274,723	18,174,426	8,714,537	1,023.8	927,289	418 858	411,006	34.2	153,388	163,753	4.3	144,332	301,493
Rhode Island	1,996,708	1,014,572	3,144,602	1,998,708	1,012,547	89.1									2,026
South Carolina	5,459,165	2,770,954	7,832,225	5,232,144	2,319,317	612.3	421,097	171,812	237,426	14.6	46,320	119,798	2.1	8,888	94,414
South Dakota	6,011,479	3,047,643	9,137,205	5,811,337	2,800,111	1,538.9	284,062	110,078	173,984	44.5		11,078	8.8	90,064	62,470
Tennessee	8,492,619	4,302,991	13,369,285	8,492,543	3,839,608	490.9	369,442		369,442	5.4		43,164	5.9	76	50,776
Texas	24,244,024	12,291,253	37,518,234	23,907,965	11,731,914	2,772.8	543,093	284,494	223,387	7.2		13,038	7.3	51,565	322,913
Utah	4,194,708	2,132,691	7,338,246	4,160,916	2,094,401	590.9	70,718	32,291	38,290					1,500	
Vermont	1,867,573	948,007	3,144,725	1,863,531	924,950	140.3	21,644	3,922	17,722	.7				121	5,335
Virginia	7,416,757	3,765,387	11,586,281	7,234,304	3,345,109	601.4	189,561	8,575	180,986	22.4	79,615	157,214	25.6	34,264	82,078
Washington	6,115,867	3,106,412	9,369,715	6,100,928	3,022,752	302.7	46,596		46,596		11,114	14,748	.3	3,825	22,315
West Virginia	4,474,234	2,280,335	6,115,399	4,315,121	1,514,235	209.9	735,027	83,534	594,986	12.5		66,425	.7	75,579	104,689
Wisconsin	9,724,881	4,941,837	15,415,670	9,716,001	4,875,594	619.7	24,316		24,316			7,915		8,880	34,012
Wyoming	4,501,327	2,287,712	6,879,280	4,451,922	2,218,377	1,037.7	5,781	5,780		.3		33,085		43,624	36,250
District of Columbia	1,918,469	973,842	2,878,699	1,909,584	968,979	22.3	8,885	8,885							4,863
Hawaii	1,871,062	949,778	2,693,451	1,870,383	264,953	51.1	650,838		646,859	4.8		14,000		679	23,966
TOTALS	394,000,000	200,000,000	618,053,780	386,537,691	176,496,131	34,758.4	22,487,226	4,852,641	15,526,771	588.6	897,711	3,250,642	152.4	1,711,957	4,726,456

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 10 DECEMBER 1936



APPARATUS USED IN DETERMINING COEFFICIENTS OF FRICTION

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Vol. 17, No. 10 December 1936

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

DETERMINATION OF COEFFICIENTS OF FRICTION OF SLIDING BEARINGS FOR BRIDGES

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by GEORGE W. DAVIS, Associate Engineer of Tests

EXPANSION and contraction in bridge superstructures are generally provided for by means of bearings at one end which permit the structure to move longitudinally with respect to its supports. For the smaller structures, these bearings are frequently of the sliding type in which a metal sole plate, rigidly connected to the superstructure, slides on a metal bearing which is rigidly connected to the substructure. The efficiency of these sliding bearings in preventing temperature stresses in the superstructure and overturning forces in the supporting substructure is inversely proportional to the frictional forces developed between the moving parts of the bridge.

As early as 1922 the Bureau of Public Roads, realizing the paucity of reliable test data as to the magnitude of these frictional forces, considered making an investigation. Some preliminary work was done in 1925 and in 1929 a more comprehensive series of tests was inaugurated. This program of tests, after several interruptions, has finally been completed and is made the subject of this report.

The coefficient of friction for sliding bearing plates was determined under varying pressures comparable to those usually employed in bridge design. Lateral pressure to cause slip was applied slowly and uniformly and the amount of movement at each slip was such as to approximate closely that caused by temperature changes in the field.

In making these tests several variables were considered, namely:

1. Materials.
2. Bearing pressures.
3. Surface finishes.
4. Direction of movement in relation to the direction in which the plates were finished.
5. The effect of lubrication.
6. The effect of rust.
7. The effect of electrolytic action on unlike materials in contact in the presence of salt water or salt air.

EFFECTS OF SEVERAL VARIABLES STUDIED IN INVESTIGATION

A more detailed discussion of the consideration given these variables follows.

1. *Materials.*—Fourteen different materials were used in these tests.

Bronzes:
  - Bronze A, A. S. T. M. Specification B22–21, class A.
  - Bronze B, A. S. T. M. Specification B22–21, class B.
  - Bronze C, A. S. T. M. Specification B22–21, class C.
  - Bronze D, A. S. T. M. Specification B22–21, class D.
  - Phosphor bronze E, A. S. T. M. Specification B22–21, class A.[1]
  - Phosphor bronze F, A. S. T. M. Specification B22–21, Class B.[1]
  - Lead bronze 22 (approximately 22 percent lead).
  - Lead bronze 17 (approximately 17 percent lead).
  - Lead bronze 8 (approximately 8 percent lead).

Steels:
  - Cast steel, A. S. T. M. Specification A27–24, class B, medium grade.
  - Rolled steel, A. S. T. M. Specification A7–29, structural steel.
  - Stainless steel.

Irons:
  - Malleable, A. S. T. M. Specification A47–30.
  - Cast, A. S. T. M. Specification A48–29, heavy castings.

The physical and chemical properties of these materials are shown in table 1.

2. *Bearing pressures.*—Tests were made under unit bearing pressures of 250, 500, 750, and 1,000 pounds per square inch.

3. *Surface finishes.*—Six surface finishes were used on the test specimens.

Planed finishes:

P_C—A coarse-planed finish produced by using a round-nosed tool with a radius of 1/16 inch, at a rate of 45 cutting strokes per minute, with a lateral feed of 0.018 inch per stroke, and taking a cut of 1/64 inch. This produced a somewhat coarse, striated finish.

P_M—A medium-planed finish produced with the same tool at the same rate and taking the same cut as above but using a lateral feed of 0.009 inch per stroke. This produced a medium smooth finish.

P_F—A smooth or fine-planed finish produced with a flat-nosed tool ⅜ inch wide, used at a rate of 45 strokes per minute, with a lateral feed of ¼ inch per stroke, and taking a cut of 0.002 inch.

Rolled or planished finish:

R—Plates were finished as under P_F with a flat-nosed tool and then rolled with a hardened steel roller ¾ inch wide and 2½ inches in diameter rigidly bolted to the head of the planer. The feed of this roller was ¼ inch per stroke and the rate 26 strokes per minute. The roller, with its face set 0.005 inch below the surface of the specimen, was fed in ¼-inch increments once transversely across the specimen. During this passage of the roller across the test plate all portions of the surface were rolled twice longitudinally, once on the forward stroke and once on the reverse stroke of the planer head. The roller was then depressed an additional 0.005 inch and

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[1] These materials as furnished were cold rolled and were classed by the manufacturer as phosphor bronze. They actually contained less phosphorus than bronzes A, B, C, and D.

TABLE 1.—*Chemical composition and physical characteristics of materials tested*

CHEMICAL COMPOSITION [1]

	Bronzes									Steel			Iron	
	A. S. T. M. Specification B22-21				Phosphor bronze		Lead bronzes			Cast, A. S. T. M. A27-24, class B, medium	Rolled, A. S. T. M. A7-29, structural	Stainless	Malleable, A. S. T. M. A47-30	Cast, A. S. T. M. A48-29, heavy
	A	B	C	D	E	F	22 percent	17 percent	8 percent					
Copper, percent	79.45	81.95	80.17	87.43	89.20	94.30	70.38	75.70	82.00					
Tin, percent	19.87	17.17	10.66	10.30	10.55	5.16	5.36	4.96	9.06					
Lead, percent	0.05	0.10	8.47	0.32			22.33	16.90	8.37					
Zinc, percent		0.20		1.65			1.68	2.21	0.24					
Iron, percent	0.23	0.18	0.15	0.15			0.14	0.14	0.21					
Phosphorus, percent	0.40	0.35	0.55	0.15	0.09	0.14				0.42	0.011	0.028		
Antimony, percent		0.05			0.16	0.40	0.10	0.09	0.12					
Carbon, percent										0.375				3.230
Sulphur, percent										0.052	0.031	0.03		0.094
Manganese, percent												0.48		
Silicon, percent												0.54		
Chromium, percent												17.30		
Nickel, percent												9.62		

PHYSICAL CHARACTERISTICS [2]

	A	B	C	D	E	F	22 percent	17 percent	8 percent	Cast steel	Rolled steel	Stainless	Malleable iron	Cast iron
Compression:														
Deformation limit, pounds per square inch	30,610	17,530	11,000	10,540	28,385	26,910	9,430	7,200	13,880					
Permanent set in 1 inch under 100,000 pounds per square inch	0.136	0.190	0.378	0.268	0.124	0.185	[3] 0.507	[4] 0.544	0.320					
Tension:														
Yield point, pounds per square inch	[illegible]	19,225	17,330	18,050	27,630	28,520	14,355	14,000	18,335	40,865	39,230	[6] 19,500–30,000	40,335	
Tensile strength, pounds per square inch	27,920	29,590	18,460	28,820	77,740	67,660	21,250	21,000	36,670	69,520	56,700	79,000–93,000	48,590	
Elongation in 2 inches, percent	0	1.00	1.75	11.00	28.00	21.00	13.00	10.00	33.00	34.00	35.70	68.0–70.0	10.17	
Reduction in area, percent										51.00		72.0–75.0		
Transverse tests:														
Deflection under 2,000 pound load, inches														0.212
Breaking load, pounds														2.970

[1] Chemical compositions shown are from analyses of materials used.

[2] All physical data for stainless steel obtained from manufacturer.

[3] Cracked at 90,070 pounds per square inch.

[4] Cracked at 97,800 pounds per square inch.

[5] None apparent before rupture.

[6] Proportional limit.

once more passed transversely across the specimen and back again, thereby subjecting all portions of the surface of the test plate to four additional longitudinal rollings. This finish removed practically all traces of the tool marks left by the planed finish.

C.R.—The cold-rolled finish as produced by the manufacturer of the plates.

M—A milled finish produced by using a spiral mill 4 inches in diameter, 5 inches long, with a 25 degree angle, 10 teeth, and a 10-inch rake. Operating at a spindle speed of 92 revolutions per minute, a lateral feed of 115 feet per minute, and a 1/64-inch cut, this mill produced a very smooth finish.

4. *Direction of movement.*—Three variations in direction of movement were used in these tests (fig. 1).

M_1—The direction of movement and the direction of finishing cuts of both plates were parallel.

M_2—The directions of finishing cuts of both plates were parallel and the direction of movement of the plates was at right angles to the finishing cuts.

M_3—The directions of the finishing cuts of the test plates were at right angles.

5. *The effect of lubrication.*—Selected combinations of plates were tested both with and without lubrication.

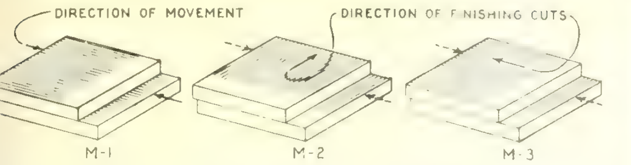
6. *Effect of rust.*—Cast iron specimens were exposed to weather until well rusted and then tested to determine the effect of rust.

7. *Electrolysis.*—The electrolytic action of stainless steel in contact with bronze and subjected to a salt solution and salt air was investigated.

Table 2 gives a summary of the conditions under which the tests were made.

PRECAUTIONS TAKEN TO INSURE EVEN APPLICATION OF BEARING PRESSURE AND THRUST

The coefficients of friction of the various materials were determined by means of a special apparatus designed and built by the Bureau. This device was used in conjunction with a universal testing machine and is shown schematically in figure 2. It consists essentially of a hydraulic jack for applying horizontal thrust, a calibrated beam for measuring this thrust, and the necessary steel framework for holding the various parts and the test specimens in their proper relative positions. Vertical loads or bearing pressures were applied by means of the universal testing machine, transmitted through two heavy car springs and a spherical bearing block. Two movable test plates, 4 by 4 by 7/8 inches, and two fixed plates, 4 by 4½ by 7/8 inches, were used in each test. The two fixed plates were encircled by the steel frame, which supported the calibrated beam that served as a reaction for the hydraulic jack. The two movable plates were inset in the top and bottom of a cylindrical movable member, which was free to move under the thrust exerted by the hydraulic jack.



JRE 1.—Relation of Direction of Movement to Direc-
ons of Finishing Cuts for Bearing Plates Tested.

LE 2.—*Materials and finishes used, direction of movement, and other test conditions*

Combination of materials		Finishes used						Direction of movement			Lubrication	Number of tests
A	A	Pc	PM	PF	M	R	...	1	2	3	UL	30
B	B	Pc	PM	PF	M	R		1			UL	[illegible]
C	C	Pc	PM	PF	M	R		1			UL	10
D	D	Pc	PM	PF	M	R		1	2	3	UL	30
A	B	...		PF			...	1			U	1
A	C	...		PF				1			U	1
A	D	...		PF				1			U	1
B	C	...		PF				1			U	1
B	D	...		PF				1			U	1
C	D	...		PF				1			U	1
A	C. S.			PF	M	R		1			UL	[illegible]
B	C. S.			PF				1			U	1
C	C. S.			PF				1			U	1
D	C. S.			PF	M	R		1			UL	[illegible]
A	R. S.	Pc	PM	PF	M			1			UL	[illegible]
B	R. S.			PF	M			1			U	[illegible]
C	R. S.			PF	M			1			U	[illegible]
D	R. S.	Pc	PM	PF	M			1			UL	[illegible]
C. S.	C. S.	Pc		PF	M			1	2	3	UL	[illegible]
C. S.	R. S.	Pc		PF	M			1			UL	[illegible]
R. S.	R. S.	Pc		PF	M			1	2	3	UL	[illegible]
M. I.	M. I.			PF	M			1			UL	[illegible]
M. I.	C. I.			PF	M			1			U	[illegible]
C. I.	C. I.			PF	M			1			U	[illegible]
C. S.	M. I.			PF	M			1			U	[illegible]
C. S.	C. I.			PF	M			1			U	[illegible]
R. S.	M. I.			PF	M			1			U	[illegible]
R. S.	C. I.			PF	M			1			U	[illegible]
P. B. E.	P. B. E.		PM				C. R.	1		[illegible]	U	[illegible]
P. B. E.	L. B. 22		PM					1			U	[illegible]
P. B. F.	P. B. F.		PM				C. R	1		[illegible]	U	[illegible]
L. B. 22	L. B. 22	Pc						1			U	1
L. B. 17	L. B. 17	Pc						1			U	1
L. B. 8	L. B. 8	Pc						1			U	[illegible]
L. B. 22	Stl. S.		PM					1			U	[illegible]
Stl. S.	C.		PM					1			U	[illegible]
Total												190

rfaces rusted.
mbols apply to but 1.
ymbols used are explained as follows:
etals:
A = Bronze A, A. S. T. M. specification B22–21, class A.
B = Bronze B, A. S. T. M. specification B22–21, class B.
C = Bronze C, A. S. T. M. specification B22–21, class C.
C. I. = Cast iron, A. S. T. M. specification A48–29, heavy.
C. S. = Cast steel, A. S. T. M. specification A27–24, class B medium.
D = Bronze D, A. S. T. M. specification B22–21, class D.
M. I. = Malleable iron, A. S. T. M. specification A47–30.
L. B. 22 = Lead bronze 22 percent.
L. B. 17 = Lead bronze 17 percent.
L. B. 8 = Lead bronze 8 percent.
P. B. E. = Phosphor bronze, A. S. T. M. specification B22–21, class A.
P. B. F. = Phosphor bronze, A. S. T. M. specification B22–21, class B.
R. S. = Rolled steel, A. S. T. M. specification A7–29, structural.
Stl. S. = Stainless steel.
nish:
Pc = Coarse-planed finish.
PM = Medium-planed finish.
PF = Fine-planed finish.
M = Milled finish.
R = Rolled or planished finish.
C. R. = Cold-rolled finish as manufactured.
rection of movement:
1—Movement and finishing cuts parallel.
2—Finishing cuts parallel, movement normal to direction of finishing cuts.
3—Finishing cuts at right angles.
brication:
U = Unlubricated.
UL = Tests were made with both lubricated and unlubricated plates.

he operation of the apparatus was as follows: The able member with its two inset movable plates was ed between the two fixed plates. The desired ing pressure was applied to the contact faces of the plates by lowering the head of the testing machine. zontal thrust was then applied (by means of the aulic jack) to the movable member at a point vay between the contact faces of the two pairs of plates (fig. 3). The magnitude of this thrust was indicated by the deflection of the calibrated beam. Since the two fixed plates were ½ inch longer, in the direction of thrust, than the two movable plates, it was possible for slip to occur and still maintain full contact between the faces.

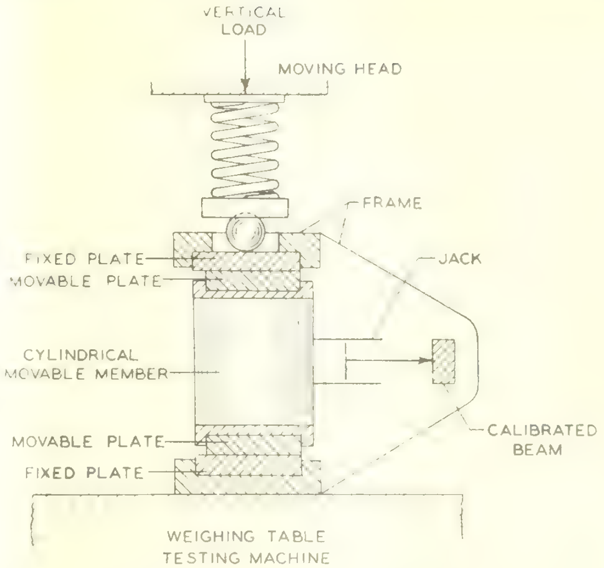


Figure 2.—Schematic Drawing of Apparatus Used Determine Coefficient of Friction.

The hydraulic jack was activated by a booster (a long-stroke, small-bore cylinder and piston) similar to those used in pressure lubrication, the system being first filled by means of a conventional hydraulic pump. The use of the booster to apply the final pressure to cause slip allowed a steady pressure to be applied without the pulsations usually caused by the strokes of a pump. The interposition of the two heavy car springs between the head of the testing machine and the bearing blocks prevented oscillation of the beam of the testing machine during tests.

The deflection of the calibrated beam was measured by means of a micrometer dial graduated to $\frac{1}{10000}$-inch divisions, one division on the dial being equivalent to 22 pounds of thrusting force. Inasmuch as the horizontal thrust measured by the calibrated beam was forced to overcome the friction existing between the contact faces of the two pairs of test plates under known unit bearing pressures, the thrust applied to each pair of plates was only one-half of that indicated by the dial reading.

The total thrusts required to overcome the initial frictional resistance under each of the unit bearing pressures were used in determining the coefficient of friction.

Definitions of the nomenclature used in this report are as follows:

Slip.—A single movement of the movable plates under lateral thrust while subject to some known bearing pressure was termed a slip.

Test.—A test comprised 15 sets of 20 slips, i. e., 300 independent slips under each of the unit bearing pressures used, other variables such as materials, finish, direction of movement, and state of lubrication being constant.

Test series.—A test series is composed of all tests made of any one combination of materials under varying conditions of finish, direction of movement, and state of lubrication.

INVESTIGATION INCLUDED STUDY OF UNLUBRICATED, LUBRICATED AND RUSTED PLATES

Tests of unlubricated plates.—In all tests the two movable plates were 4 by 4 by ⅞ inches and the two fixed plates were 4 by 4½ by ⅞ inches. In each test newly surfaced plates were used. Before testing, the plates were thoroughly washed in naphtha to remove surface grease, moisture, or any foreign matter. The plates were then inserted in the testing apparatus and a bearing load of 4,000 pounds (250 pounds per square inch, on the 16 square inches of contact area of the plates) was imposed by lowering the head of the testing machine. Thrust was then applied through the hydraulic jack by means of the booster until slip occurred. The point of slip was considered to be that point at which the needle of the micrometer dial started to recede. Successive thrusts were applied and readings noted until a succession of 20 slips had been recorded. Each set of 20 slips caused a shifting of the movable plates over the fixed plates of approximately ½ inch.

After each set, the plates were removed, rinsed in naphtha, turned horizontally through 180 degrees and replaced in the apparatus. The plates were thus kept free from lubricant and were subjected to sliding in opposite directions as would be the case in actual service. After 15 sets of 20 slips the bearing pressure was increasd to the next higher value. The schedule just described was carried out for bearing pressures of 250, 500, 750, and 1,000 pounds per square inch, respectively, and this constituted one test, the plates being resurfaced before being used again.

In every case where seizure was apparent the fact was noted, in order that the percentage of movements or slips in which seizure occurred during the course of each test might be determined. Seizure was determined either by audible chattering or by jumping of the plates as indicated by the micrometer dial. The thicknesses of all plates were measured by means of micrometer calipers at four points both before and after each test.

Tests of lubricated plates.—The procedure followed in making tests of lubricated plates was identical with that used in testing unlubricated plates with the following exceptions. After the newly surfaced plates were washed in naphtha a thin coating of graphite cup grease was applied to their contact faces. They were placed in the testing apparatus and a bearing pressure of 4,000 pounds, or 250 pounds per square inch, was applied. The plates were slid in successive slips once across the fixed plates to distribute the grease evenly and to force any excess from between the plates. The plates were then removed, reversed, and successive slips were made as in the tests of unlubricated plates, but with the original coating of lubricant intact.

Four cast-iron plates with the smooth-planed finish (Pf) and four with a milled finish (M) were exposed to the weather, including snow and rain, for 76 and 56 days, respectively. This exposure produced a thick coating of rust. The plates were rubbed against each other with hand pressure to remove superficial rust and the friction tests were then made. The friction developed in both cases was so large that only the lowest unit bearing pressure (250 pounds per square inch) was applied. The plates were reversed between each set of 20 slips, and the rust loosened from the contact surfaces was lightly brushed off with a cloth between each series of slips. A comparison of the thickness of these plates as measured before and after e posure to the weather and after friction tests had bee completed indicated that the wear shown during th tests was caused by the loosening of surface rust, a no measurable reduction in original thickness was note

The following procedure was adopted in determinin the coefficient of friction in each test. Curves wer plotted for each of the four loadings, mean values o the total thrust necessary to overcome the frictio existing on the 16 square inches of bearing surface, fo each of the 15 sets of 20 slips, being used as ordinate while the 15 sets were plotted at uniform spacings a abscissae.

COEFFICIENT OF FRICTION REMAINED CONSTANT UNDER VARIOUS BEARING PRESSURES

The averages of the mean values of thrust of the las 10 sets (200 individual slips) were used in determinin the coefficient of friction, the first 5 sets being con sidered as adjusting or wearing-in values. These ave ages were plotted on abscissa, proportional to th bearing pressures and a mean curve was drawn throug the resulting four points and the zero point. In a cases this curve was a straight line, which indicate that the value of the coefficient of friction remain constant under varying unit pressures. The maximu and minimum variations above and below the mean o any set of slips were shown by the limits of the vertica lines, drawn to scale, extending above and below th mean values as plotted.

It obviously being impracticable to reproduce th curves representing all tests performed in this investi gation, typical curves developed in the manner jus described are shown in figures 4, 5, 6, and 7. Th results of all tests are compiled in table 3 in ascendin order of coefficients of friction for tests without lubri cation. In the column headed "Average maximu variations from mean thrust", the values shown wer derived as follows: The average of the thrusting force necessary to cause movement for the last 10 sets o slips, or of 200 individual slips, under a unit bearin pressure of 500 pounds per square inch, was used as base. The maximum variations in thrusting forc above and below the mean thrust for each of the las 10 sets of slips were averaged and these two average expressed as plus or minus percentages of the base.

The values shown for the variations from mean thrus are for the 500 pounds per square inch unit pressur only, as this value is considered to be a representativ value for all loadings. Variations for the tests o lubricated plates are omitted. In the majority o cases the variation for the lubricated plates was greate than in the case of unlubricated plates.

For the purpose of discussion, results for the 11 combinations tested, as arranged in table 3 and excluc ing the two tests of rusted plates (24–2 and 24–4) wer arbitrarily divided into three equal groups of 37 com binations each. These groups are designated 1, 2, an 3, and contain the low, intermediate, and high values o the coefficient of friction, respectively.

In determining the effect of lubrication on the valu of the coefficient of friction between flat plates, data fro 77 tests both with and without lubrication were avai able for comparison. Examination of the individua curves for each of these 77 tests gave the followin indications.

TABLE 3.—*Coefficients of friction and other data for the various plates tested*

GROUP 1—LOW COEFFICIENTS OF FRICTION

ries test ber[1]	Metals used	Surface finish	Direction of movement	Coefficient of friction		Average maximum variations from mean thrust; 500 pounds per square inch unit bearing pressure no lubrication		Wear		[illegible]—Percentage of [illegible] seized							
										Lubricated—Unit bearing pressure—				No lubrication—Unit bearing pressure—			
				Lubricated	No lubrication	+	−	Lubricated	No lubrication	250 pounds	500 pounds	750 pounds	1,000 pounds	250 pounds	500 pounds	750 pounds	1,000 pounds
						Percent	*Percent*	*Inches*	*Inches*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	C-R. S.	P_F	1		0.106	2.1	1.0										
	L. B. 22-Stl. S.	P_M	1		.110	4.0	2.4										
	C-C. S.	P_F	1		.112	1.7	1.4										
	C-Stl. S.	P_M	1		.116	2.5	1.3										
	C-R. S.	M	1		.118	3.2	1.4										
6	A-R. S.	P_F	1	0.121	.123	1.1	1.5										
8	A-R. S.	M	1	.110	.127	1.1	.7										
	B-R. S.	P_F	1		.128	1.6	1.5										
4	A-R. S.	P_M	1	.122	.128	1.7	.9										
	L. B. 22-L. B. 22.	P_C	1		.128	1.8	1.5		0.001								
	L. B. 17-L. B. 17.	P_C	1		.130	1.0	2.7		F=0 M=.0005								
	P. B. E.-L. B. 22.	P_M	1		.132	3.3	1.7										
	L. B. 8-L. B. 8.	P_C	1		.132	1.4	1.4										
	B-R. S.	M	1		.132	.7	1.6										
2	A-C. S.	P_F	1	.115	.134	2.6	1.0		A=0 C. S.=.001								
	A-C.	P_F	1		.134	1.2	3.6										
	A-C. S.	R	1	.123	.135	2.9	1.3										
8	D-R. S.	M	1	.108	.135	.7	1.1										
	B-C. S.	P_F	1		.136	1.0	2.4										
2	D-R. S.	P_C	1	.121	.137	1.4	.9		D=.001 R. S.=.002								
	C-C.	P_M	1	.126	.137	1.3	1.3			2	12	16	[illegible]				
4	A-C. S.	M	1	.112	.138	1.2	1.0										
2	A-R. S.	P_C	1	.116	.138	2.8	1.2		A=.001 R. S.=.002								
	A-A.	P_M	1	.126	.138	1.4	2.7										
	A-B.	P_F	1		.138	1.1	2.5										
	B-C.	P_F	1		.139	1.8	2.4										
20	D-D.	M	1	.110	.140	1.4	2.1										
4	D-C. S.	M	1	.110	.140	1.3	1.9										
16	A-A.	P_F	2	.162	.143	3.1	3.8			19	31	25	18				
30	A-A.	R	3	.122	.146	1.7	1.2										7
22	D-D.	M	2	.112	.146	1.5	4.6										
24	D-D.	M	3	.122	.146	1.5	1.6										
	B-D.	P_F	1		.148	1.5	4.1										
	C-C.	R	1	[2].185	.148	1.4	1.9			52	89	92	94	[illegible]	12	12	12
20	A-A.	M	1	.107	.148	.9	1.8										
	B-B.	P_M	1	.148	.150	1.1	2.8										
	C-C.	M	1	.164	.150	1.1	1.2			4	14	38	38				

GROUP 2—INTERMEDIATE COEFFICIENTS OF FRICTION

ries test ber[1]	Metals used	Surface finish	Direction of movement	Coefficient of friction, Lubricated	Coefficient of friction, No lubrication	+	−	Wear, Lubricated	Wear, No lubrication	Lubricated 250 pounds	Lubricated 500 pounds	Lubricated 750 pounds	Lubricated 1,000 pounds	No lubrication 250 pounds	No lubrication 500 pounds	No lubrication 750 pounds	No lubrication 1,000 pounds
1	D-C. S.	P_F	1	0.121	0.150	0.9	2.1										
	A-A.	P_C	3	.139	.150	3.0	1.2										
16	C. S.-C. S.	M	2	.136	.150	4.0	4.5		0.001					0	1	12	[illegible]
3	C. I.-C. I.	M	1		.150	2.9	4.5									39	25
12	A-A.	P_M	3	.132	.151	1.2	.9										
	A-D.	P_F	1		.152	1.5	3.0										
	D-D.	P_M	1	.148	.152	1.0	2.0										
34	A-A.	P_F	1	.128	.152	1.3	1.6										
78	A-A.	P_F	3	.134	.154	1.7	1.4										2
34	A-A.	M	3	.128	.154	.9	1.4									2	9
56	A-A.	R	1	.146	.157	1.7	2.3										
1	C. I.-C. I.	P_F	1		.157	4.2	4.8									4	12
	A-A.	P_C	1	.132	.157	1.5	.9		F=0 M=.002								
	D-D.	P_C	3	.154	.158	7.5	1.9		.001								
3	D-R. S.	P_M	1	.134	.158	2.4	4.0		.001								
	C-C.	P_F	1	[3].190	.158	1.4	2.4			73	81	97	100				
2	C. S.-M. I.	M	1		.158	4.7	7.0							0	5	24	26
5	D-R. S.	P_F	1	.118	.159	1.0	2.6										
	A-A.	P_M	2	.136	.161	17.3	7.5		F=0 M=.001	3	48	57	45	[illegible]	97	98	88
	B-B.	P_C	1	.144	.161	2.1	1.7	.001									
	B-B.	P_F	1	.154	.162	1.0	2.3										
1	M. I.-M. I.	P_F	1	.152	.162	5.3	6.8							0	4	45	54
	A-A.	M	2	.125	.162	2.1	1.4										
	C. S.-C. S.	M	3	.144	.162	8.8	6.5							5	9	35	53
1	P. B. F.-P. B. F.	C. R.	1		.162	3.5	2.8										
	D-D.	P_C	1	.130	.163	1.9	1.4										
	A-A.	R	2	.124	.164	2.2	3.2										29
1	C-D.	P_F	1		.165	1.8	2.9										
	D-D.	P_M	3	.162	.166	1.3	1.5										
	B-B.	M	1	.121	.167	1.2	1.8										
1	C. S.-M. I.	P_F	1		.167	1.9	3.7							[illegible]	56	60	70
	D-D.	R	2	.130	.168	2.3	5.3							0	13	41	66
2	P. B. F.-P. B. F.	P_M	3		.170	2.7	2.6							0	11	69	89
	C-C.	P_C	1	.161	.172	.9	.5	.002									
	D-D.	P_M	2	.142	.172	7.9	6.5		F=0 M=.001	10	[illegible]	39	48	[illegible]	100	100	100
	B-B.	R	1	.132	.172	1.6	.9							0	0	1	[illegible]
	D-D.	R	1	.091	.172	1.6	1.9										

---

[1] irst number indicates series; remaining numbers indicate individual tests. Where 2 test numbers are shown, they refer to tests of lubricated and unlubricated te espectively.

[2] ubricant removed, coefficient of friction dropped to 0.170.

[3] ubricant removed, coefficient of friction dropped to 0.152.

Table 3.—*Coefficients of friction and other data for the various plates tested*—Continued

GROUP 3—HIGH COEFFICIENTS OF FRICTION

Series and test number	Metals used	Surface finish	Direction of movement	Coefficient of friction		Average maximum variations from mean thrust; 500 pounds per square inch unit bearing pressure; no lubrication		Wear		Seizure—Percentage of slips seized							
										Lubricated—Unit bearing pressure—				No lubrication—Unit bearin			
				Lubricated	No lubrication	+	−	Lubricated	No lubrication	250 pounds	500 pounds	750 pounds	1,000 pounds	250 pounds	500 pounds	750 pounds	1,0 pou
						Percent	Percent	Inches	Inches	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Perc
21-17-18	R. S.-R. S.	M	3	0.141	0.174	13.2	12.0							19	43	42	
4-5-6	D-C. S.	R	1	.110	.174	2.5	5.1										
19-1-2	C. S.-C. S.	PC	1	.150	.174	8.7	3.2	0.001	0.002	0	5	10	26	1	1	2	
23-1	M. I.-C. I.	PF	1		.174	2.0	4.6		M. I.=.001 C. I.=0					0	0	18	
25-2	M. I.-C. I.	M	1		.174	6.8	2.2										
29-2	P. B. E.-P. B. E	PM	3		.175	2.2	4.4							0	8	82	
21-15-16	R. S.-R. S.	M	2	.140	.176	17.1	12.1							34	41	75	
22-3-4	M. I.-M. I.	M	1	.135	.178	8.6	5.9							31	40	49	
20-5-6	C. S.-R. S.	M	1	.130	.182	11.6	7.8							49	76	75	
27-2	R. S.-M. I.	M	1		.182	7.5	5.3							52	63	78	
27-1	R. S.-M. I.	PF	1		.183	14.8	9.6							43	62	77	
19-13-14	C. S.-C. S.	M	1	.131	.186	12.2	7.4		.001					36	55	76	
19-11-12	C. S.-C. S.	PF	3	.145	.187	19.8	10.6						2	42	69	83	
4-15-16	D-D	PF	2	.162	.190	4.0	5.5							0	46	78	
19-5-6	C. S.-C. S.	PC	3	.150	.190	16.7	13.4	.001	F=.001 M=.002	10	14	22	44	15	40	54	
4-29-30	D-D	R	3	.131	.194	2.0	3.5							0	26	63	
29-1	P. B. E.-P. B. E.	C. R.	1		.195	8.4	7.6							0	2	3	
19-9-10	C. S.-C. S.	PF	2	.141	.198	17.8	9.9							29	87	91	
26-2	C. S.-C. I.	M	1		.203	1.6	3.3							0	18	58	
4-17-18	D-D	PF	3	.176	.204	5.4	10.4	F=0 M=.001						6	57	61	
20-1-2	C. S.-R. S.	PC	1	.160	.208	13.0	9.7	.001	.002	10	10	21	30	0	17	35	
4-13-14	D-D	PF	1	.141	.210	4.7	9.5		.001					63	78	84	
21-5-6	R. S.-R. S.	PC	3	.166	.211	17.9	13.0		.001	8	15	43		25	56	66	
21-13-14	R. S.-R. S.	M	1	.134	.215	15.0	17.6							23	48	77	
19-7-8	C. S.-C. S.	PF	1	.140	.218	18.2	15.3							51	81	90	
21-11-12	R. S.-R. S.	PF	3	.165	.220	19.0	14.7			38	68	72	76	80	89	90	
26-1	C. S.-C. I.	PF	1		.220	15.9	17.2							70	78	89	
21-1-2	R. S.-R. S.	PC	1	.154	.221	16.8	16.0	F=0 M=.001	.001	6	15	26	35	19	59	66	
20-3-4	C. S.-R. S.	PF	1	.160	.238	17.4	16.8			6	26	52	63	91	93	97	
28-2	R. S.-C. I.	M	1		.239	8.7	4.8		C. I.=0 R. S.=.001					81	86	93	
21-9-10	R. S.-R. S.	PF	2	.156	.243	12.6	13.4			3	8	13	56	28	64	81	
21-7-8	R. S.-R. S.	PF	1	.155	.266	12.8	16.6			2	8	49	63	69	88	98	
28-1	R. S.-C. I.	PF	1		.275	9.4	11.0		C. I.=0 R. S.=.001					87	92	90	
1-3-4	A-A	PC	2	.320	.340	Seized				100				100			
19-3-4	C. S.-C. S.	P	2	.241	.392	Seized		.001		92				100			
4-3-4	D-D	P	2	.219	.418	Seized				92				100			
21-3-4	R. S.-R. S.	PC	2	.156	.456	Seized		F=0 M=.001	F=0 M=.001	100				100			

TESTS OF RUSTED PLATES

4-4	C. I.-C. I.	M	1		[4] .488	Seized			[5] .001					100			
21-2	C. I.-C. I.	PF	1		[4] .598	Seized			[5] .002					97			

[4] Surfaces rusted by exposure.

[5] Rust only wore off, no decrease in original thickness.

The symbols used are explained as follows:

Metals—
- A=Bronze, A. S. T. M. Specification B22-21, class A.
- B=Bronze, A. S. T. M. Specification B22-21, class B.
- C=Bronze, A. S. T. M. Specification B22-21, class C.
- C. I.=Cast iron, A. S. T. M. Specification A48-29, heavy.
- C. S.=Cast steel, A. S. T. M. Specification A27-24, class B medium.
- D=Bronze, A. S. T. M. Specification B22-21, class D.
- L. B. 22=Lead bronze-22 percent lead.
- L. B. 17=Lead bronze-17 percent lead.
- L. B. 8=Lead bronze-8 percent lead.

Direction of movement—
- 1=Direction of movement and direction of finishing cuts parallel.
- 2=Direction of movement at right angles to finishing cuts, finishing cuts parallel.
- 3=Direction of the finishing cuts at right angles.

Metals—Continued.
- M. I.=Malleable iron, A. S. T. M. Specification A47-30.
- P. B. E.=Phosphor bronze, A. S. T. M. Specification B22-21, class A.
- P. B. F.=Phosphor bronze, A. S. T. M. Specification B22-21, class B.
- R. S.=Rolled steel, A. S. T. M. Specification A7-29, structural grade.
- Stl. S.=Stainless steel.

Wear—
- M=Movable plate.
- F=Fixed plate.

In 60 tests of unlubricated plates the mean values of the coefficient of friction, for the last 10 sets of slips under each of the four loads, showed a tendency to remain constant or to decrease slightly, and in 17 tests this value showed a tendency to increase slightly, while in the tests of lubricated plates this value for 44 remained constant or decreased and 33 showed a marked tendency to increase.

Figure 7 shows data from one of the tests in whi this tendency for the resistance to increase as the te progressed is evident. The example given is a typic rather than an extreme case.

In four tests (1-15-16, 3-5-6, 3-7-8, and 3-9-10) t lubricated plates showed greater friction than the u lubricated plates, and in all four cases the lubricat plates seized while unlubricated plates seized in on

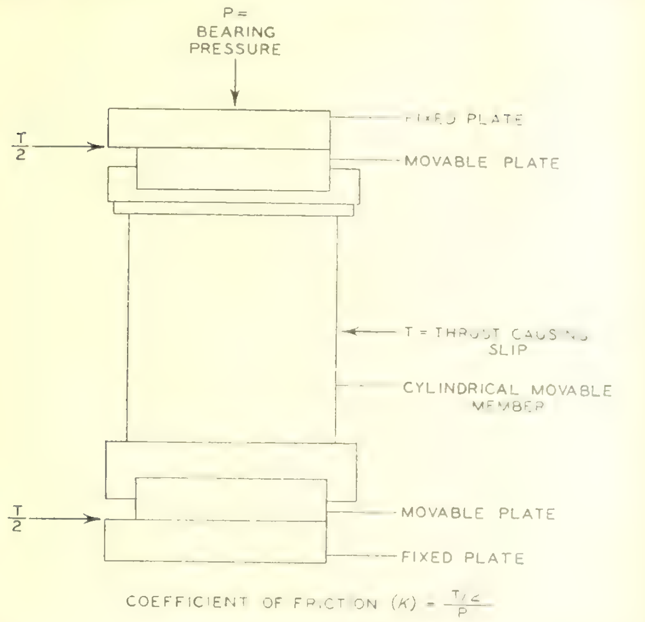


FIGURE 3.—ARRANGEMENT OF BEARING PLATES DURING TEST, SHOWING THE FORCES INVOLVED IN CALCULATING THE COEFFICIENT OF FRICTION (k).

one case. In two tests (3–5–6 and 3–9–10), where the friction with lubrication was greater than without lubrication, all lubricant was washed off with naphtha at the end of the tests and a single set of 20 slips under each of the four loadings was run without lubricant. These results showed a definite decrease in the coefficients of friction (from 0.190 and 0.185, when lubricated, to 0.152 and 0.170, respectively) with no lubrication.

In group 1 of table 3 there were 21 combinations that were tested both with and without lubrication. Of these 21 combinations, the coefficients of friction of the lubricated plates in 6 cases showed a tendency to increase and in 15 cases a tendency to remain constant as the tests progressed, while in the same 21 combinations, where unlubricated plates were used, only 2 cases showed a tendency to increase, 16 remained constant, and 3 decreased.

In group 2 of table 3 there were 29 combinations available for a similar comparison. In these 29 tests the tendencies of the coefficients of friction to vary were as follows: When lubricated plates were used, 18 showed a tendency to increase, 10 to remain constant, and 1 to decrease. With no lubrication, 3 combinations showed a tendency to increase, 23 to remain constant, and 3 to decrease.

In group 3 of table 3, 27 combinations were available for comparison and the following tendencies to vary were noted. With lubricated plates 9 combinations showed a tendency to increase, 17 to remain constant, and 1 to decrease. With the unlubricated plates, 12 combinations showed a tendency to increase, 12 to remain constant, and 3 to decrease.

LUBRICANT OF QUESTIONABLE PERMANENT VALUE IN REDUCING FRICTION

Considering groups 1 and 2, as comprising the most desirable combinations, table 4 shows the general tendencies of the coefficients to vary and permits a comparison to be made between the lubricated and unlubricated plates in this respect.

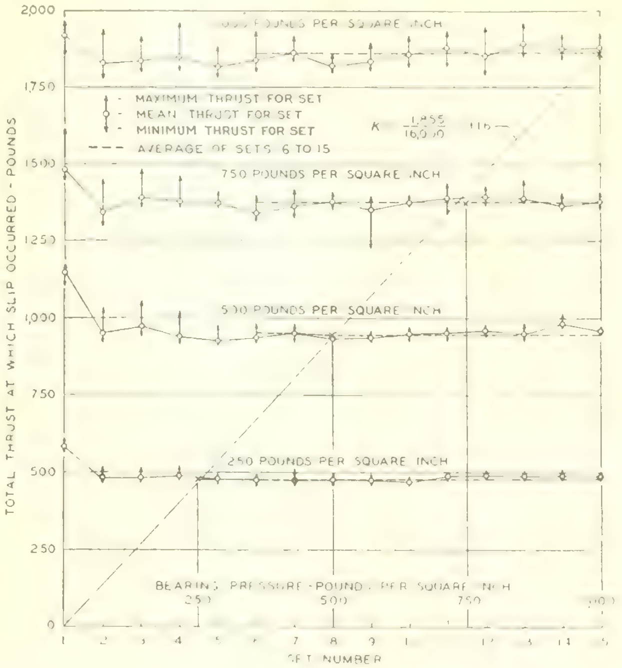


FIGURE 4.—RELATIONS BETWEEN BEARING PRESSURE AND THRUST AT WHICH SLIP OCCURRED FOR TEST SERIES 36, NO. 1, SHOWING DERIVATION OF COEFFICIENT OF FRICTION (k): BRONZE C ON STAINLESS STEEL; MEDIUM-PLANED FINISH; MOVEMENT PARALLEL TO FINISHING CUTS; NO LUBRICATION; NO WEAR; AND NO SEIZURE.

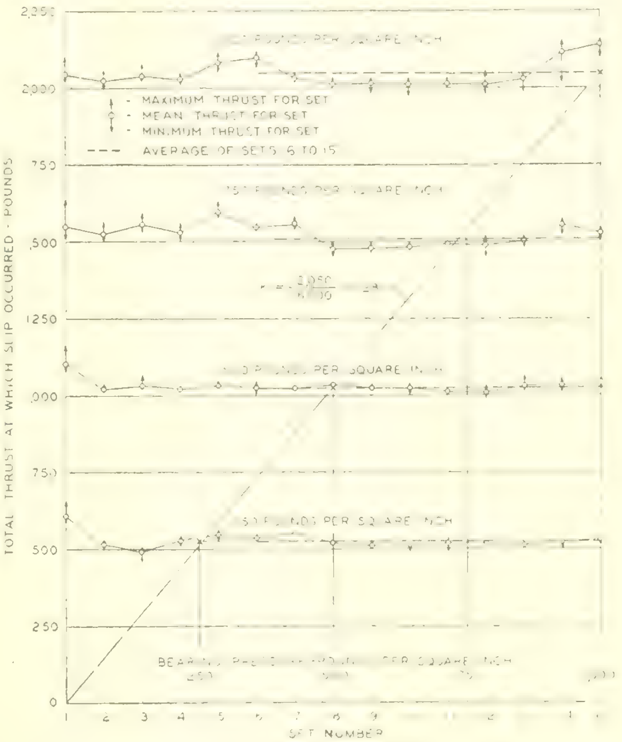


FIGURE 5.—RELATIONS BETWEEN BEARING PRESSURE AND THRUST AT WHICH SLIP OCCURRED FOR TEST SERIES 16, NO. 1. BRONZE B ON ROLLED STEEL; FINE-PLANED FINISH; MOVEMENT PARALLEL TO FINISHING CUTS; NO LUBRICATION; NO WEAR; AND NO SEIZURE.

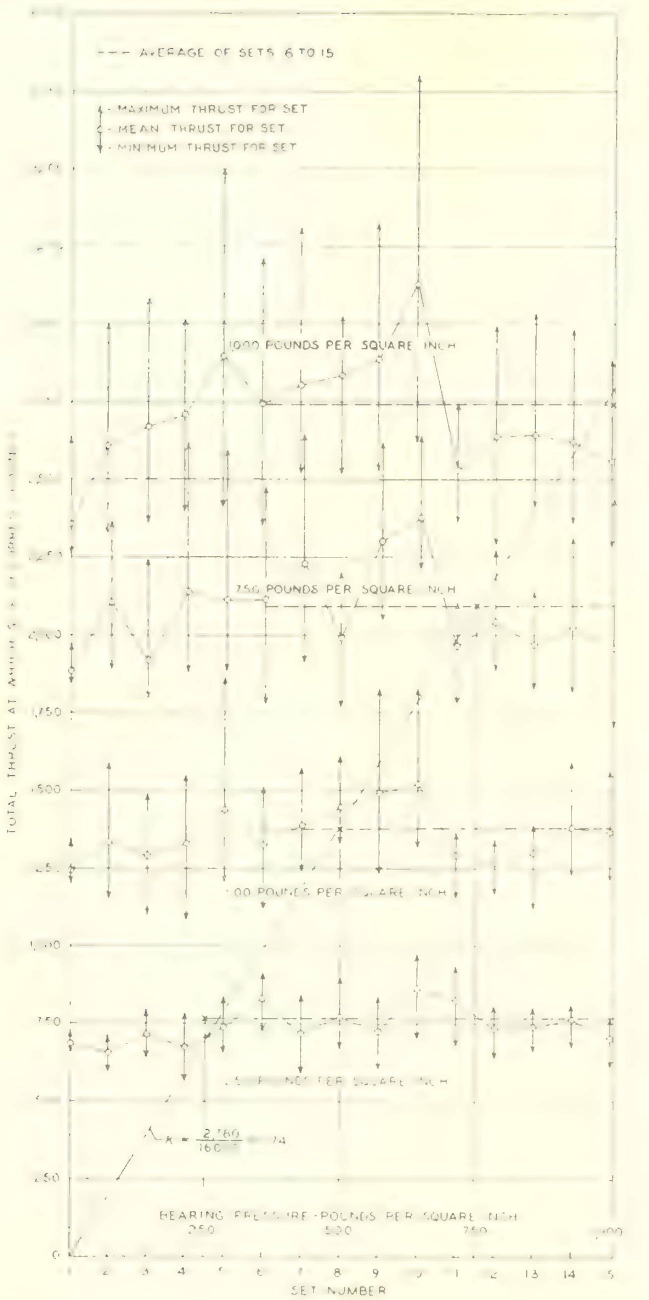


Figure 6.—Relations Between Bearing Pressure and Thrust at Which Slip Occurred for Test Series 21, No. 17. Rolled Steel on Rolled Steel; Milled Finish; Movement—Finishing Cuts at Right Angles; No Lubrication; No Wear; Seizure at 250 Pounds Per Square Inch, 19 Percent of Slips; at 500 Pounds, 43 Percent; at 750 Pounds, 42 Percent; and at 1,000 Pounds per square Inch, 70 Percent of Slips.

Table 4.—*Variations in coefficient of friction in tests of lubricated and unlubricated plates*

Condition of plates	Variation in coefficient of friction during last 20 sets of slips		
	Constant	Increased	Decreased
	Number of tests	*Number of tests*	*Number of tests*
Unlubricated	39	5	6
Lubricated	25	24	1

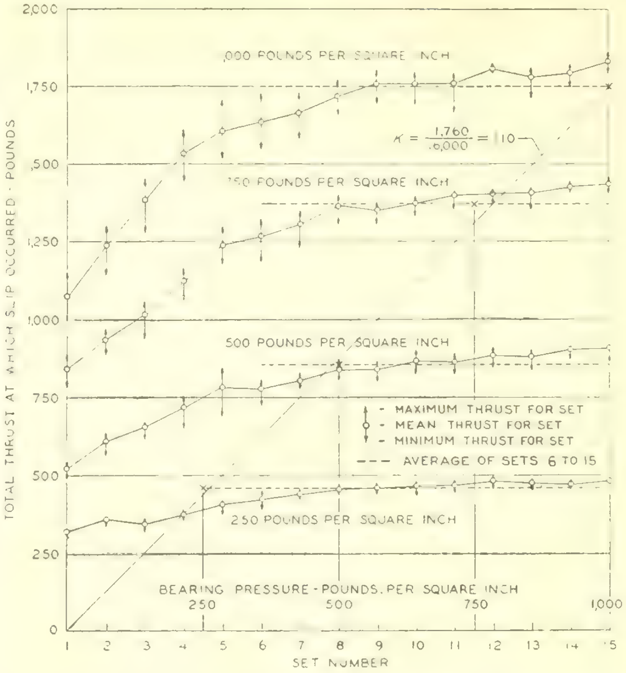


Figure 7.—Relations Between Bearing Pressure and Thrust at Which Slip Occurred for Test Series 14, No. 6. Bronze D on Cast Steel; Rolled or Planished Finish; Movement Parallel to Finishing Cuts; Plates Lubricated; No Wear; and No Seizure.

In group 1, the values for the lubricated plates are on an average 11.5 percent less than the values for the unlubricated plates, while in groups 2 and 3 the differences in favor of the lubricated plates are 13.8 percent and 28.3 percent, respectively.

It appears that, although lubrication with the type of lubricant used causes an initial decrease in friction, with continued movement the lubricant is forced out from between the plates and the friction increases until it may equal or surpass that of the unlubricated plates. The smoother the finish, the sooner the beneficial effects of lubrication appear to be dissipated.

Inasmuch as the beneficial effects of lubrication for the most desirable combinations (groups 1 and 2) are small and since in many of the tests these effects decreased during the comparatively limited number of movements made in a test, it seems probable that the use of a single application of graphite grease, or other lubricant which will flow, is of but little, if any, permanent value when used between flat plates subject to load intensities such as used in these tests.

In considering the effects of surface finish on friction, 19 groups of tests with machined surfaces are available for comparison. In making the comparison, tests of unlubricated plates, with direction of movement and direction of finishing cuts parallel, were used. The results of these tests are assembled in table 5 in four groups:

1. Like metals (ferrous).
2. Unlike metals (ferrous).
3. Like metals (bronze).
4. Unlike metals (ferrous and bronze).

In groups 1 and 2 the fine-planed finish gave the highest values of the coefficient of friction and the milled finish gave the lowest values except in the case of cast iron on cast iron, for which the lowest value was

Table 5.—*Effect of surface finish on magnitude of coefficient of friction; all plates unlubricated; direction of movement and direction of finish parallel*

GROUP 1—LIKE METALS—FERROUS

Metals	Finish	Coefficient of friction	Seizure
R. S.	P_F	[illegible]	[illegible]
	P_C	[illegible]	[illegible]
	M	.215	[illegible]
C. S.	P	.218	Yes.
	M	[illegible]	[illegible]
	P	[illegible]	[illegible]
C. I.	P	[illegible]	Yes.
	M	.150	Yes.

GROUP 2—UNLIKE METALS—FERROUS

Metals	Finish	Coefficient of friction	Seizure
R. S.-C. I.	P	[illegible]	[illegible]
	M	[illegible]	Yes.
C. S.-R. S.	P	.238	Yes.
	P	[illegible]	[illegible]
	M	.182	Yes.
C. S.-C. I.	P	[illegible]	[illegible]
	M	.203	[illegible]
R. S.-M. I.	P	[illegible]	[illegible]
	M	[illegible]	Yes.
M. I.-C. I.	P	[illegible]	Yes.
	M	[illegible]	[illegible]
C. S.-M. I.	P	[illegible]	[illegible]
	M	.158	[illegible]

GROUP 3—LIKE METALS—BRONZE

Metals	Finish	Coefficient of friction	Seizure
D	P	0.210	Yes.
	R	[illegible]	No.
	P	[illegible]	No.
	P	.152	No.
	M	.140	[illegible]
[illegible]	P	.172	Yes.
	M	.167	No.
	P	.162	[illegible]
	P	[illegible]	No.
	P	.150	[illegible]
[illegible]	P	.172	No.
	P	.158	No.
	M	.150	No
	R	[illegible]	[illegible]
	P	[illegible]	[illegible]
A	P	.157	No.
	R	.157	[illegible]
	P	.152	No
	M	.148	[illegible]
	P	[illegible]	[illegible]

GROUP 4—UNLIKE METALS—FERROUS AND BRONZE

Metals	Finish	Coefficient of friction	Seizure
D-C. S.	R	[illegible]	[illegible]
	P	[illegible]	No.
	M	[illegible]	[illegible]
D-R. S.	P	[illegible]	No.
	P	[illegible]	No.
	P	[illegible]	No.
	M	[illegible]	[illegible]
A-R. S.	P	.138	No.
	P	.128	No.
	M	[illegible]	No.
A-C. S.	P	.123	No.
	M	.138	No.
	R	[illegible]	No.
	P	.134	No.
B-R. S.	M	.132	No.
	P_F	.128	[illegible]
C-R. S.	M	[illegible]	No.
	P	.106	No.

Symbols used are:

A = Bronze A.
B = Bronze B.
C = Bronze C.
D = Bronze D.
C. I. = Cast iron.
C. S. = Cast steel.
M. I. = Malleable iron.
R. S. = Rolled steel.

given by the coarse-planed finish. Seizure was noted in 100 percent of the tests in group 1 and 92 percent of those in group 2.

In group 3 either the medium-planed or the milled finishes had the lowest values of the coefficient of friction. Seizure was noted in only 15 percent of the 20 tests comprising this group.

In group 4 the fine-planed and milled finishes gave the most satisfactory results. No seizure was noted in this group.

Tests were made of combinations of two grades of cold-rolled phosphor bronze, with surfaces as rolled at the mill. In both cases the direction of movement and the directions of finish of all plates were parallel. Phosphor bronze E showed a high coefficient of friction, falling within the highest 20 percent of all tests made. Seizure was noted in 6 percent of the slips under the maximum loads. Phosphor bronze F, under similar conditions of test, gave a coefficient of friction within the higher 50 percent of all tests made, and no seizure was noted.

An attempt to determine the comparative merits of a cold-rolled finish and a machined finish was later made. The cold-rolled phosphor bronze specimens, both E and F, were machined with a medium-planed finish (P_M) and tested in like pairs. No lubrication was used and tests were made with the direction of the finishing cuts of the contact faces at right angles (M_3). Data from former tests indicated the above finish and direction of movement to be satisfactory for use with like bronzes.

The results of these tests (series 29 and 31) are shown in the general compilation of test results in table 3. By comparing the results it will be seen that no wear was apparent in any of these tests. In the case of phosphor bronze E, the machined surfaces showed a 10-percent decrease in friction when compared with the cold-rolled finish, while in the case of phosphor bronze F the machined plates showed approximately a 5-percent increase in friction in comparison with the cold-rolled plates. Both materials, when tested with machined surfaces, showed a marked increase in the number of slips which seized, from a maximum of 6 percent to 87 percent in series 29 and from a maximum of 0 percent to 89 percent in series 31. However, the intensity of seizure, as evidenced by the lack of violence of the jump and the small distances moved under lateral thrust, was low in both tests. The percentage of maximum variation from the mean thrust at slip was lower when machined surfaces were used than when cold-rolled surfaces were used.

If due consideration is given to the variations from the mean thrust necessary to cause slip found in the several tests, and to the limited number of comparisons made for the two finishes, the limited differences in coefficient of friction found indicate no marked superiority for either finish.

MILLED FINISH WITH FINISHING CUTS AT RIGHT ANGLES FOUND MOST SATISFACTORY

Two tests were made of cast-iron plates, one with a fine-planed surface and one with a milled finish, all surfaces rusted by exposure to weather. The friction developed was excessive in both series and only under the lowest unit bearing pressure used (250 pounds per square inch) could slipping be produced.

From the results shown in table 5 the following conclusions seem reasonable:

1. A milled finish is most satisfactory when ferrous materials are used in combination.

2. A milled or medium-planed finish is most satisfactory for combinations of like bronzes.

3. A milled or fine-planed finish is most satisfactory for combinations of ferrous materials with bronzes.

In connection with these conclusions, it should be remarked that the spread of values resulting from differences in surface finish is, in general, not great and in many cases the differences between average coefficients of friction for two or more finishes on a particular combination of metals are so small as to lack significance. Fine distinctions are therefore not warranted.

There are available for purposes of comparison 16 groups of tests in which all three directions of movement were tested with the same combinations of materials. Fourteen of these groups covered the three planed and milled finishes and two groups covered the rolled or planished finish.

For each material the three coefficients of friction corresponding to the three directions of movement were arranged in order of decreasing values of the coefficients of friction and grouped under each of the surface finishes considered. These data are shown in table 6.

The 14 groups of tests covering the 3 planed finishes and the milled finish were considered as a unit, the rolled or planished finish being considered alone.

For the 14 groups of tests, summations were then made of the total number of times each of the three directions of movement occurred in the high, intermediate, and low-value groups of the coefficient of friction for each combination of material and each surface finish shown in table 6. These totals were then converted into percentages of the total number of groups of tests, which resulted in the relations between the three directions of movement shown in table 7.

TABLE 6.—*Effect of direction of movement on the magnitude of the coefficient of friction, for like metals in combination, unlubricated*

Materials used	Coarse-planed finish		Medium-planed finish		Fine-planed finish		Milled finish		Rolled or planished finish	
	Direction of movement	Coefficient of friction (*k*)	Direction of movement	Coefficient of friction (*k*)	Direction of movement	Coefficient of friction (*k*)	Direction of movement	Coefficient of friction (*k*)	Direction of movement	Coefficient of friction (*k*)
Bronze A	M_2	[1]0.390	M_2	[1]0.161	M_3	[1]0.154	M_2	0.162	M_2	[1]0.164
	M_1	.157	M_3	.151	M_1	.152	M_3	[1].154	M_1	.157
	M_3	.150	M_1	.138	M_2	.143	M_1	.148	M_3	[1].146
Bronze D	M_2	[1].448	M_2	[1].172	M_1	[1].210	M_2	.146	M_3	[1].194
	M_1	.163	M_3	.166	M_3	[1].204	M_3	.146	M_1	.172
	M_3	.158	M_1	.152	M_2	[1].190	M_1	.140	M_2	[1].168
Rolled steel	M_2	[1].456	-----	-----	M_1	[1].266	M_1	[1].215	-----	-----
	M_1	[1].224	-----	-----	M_2	[1].243	M_2	[1].176	-----	-----
	M_3	[1].211	-----	-----	M_3	[1].220	M_3	[1].174	-----	-----
Cast steel	M_3	[1].392	-----	-----	M_1	[1].218	M_1	[1].186	-----	-----
	M_2	[1].190	-----	-----	M_3	[1].198	M_2	[1].162	-----	-----
	M_1	[1].174	-----	-----	M_2	[1].187	M_3	[1].150	-----	-----

[1] Seizure occurred.

Symbols used are:
M_1 = Direction of movement and finish of plates parallel.
M_2 = Direction of finish of plates parallel, direction of movement normal to direction of finish.
M_3 = Direction of finish of plates at right angles.

It will be seen that 93 percent of the tests in which movement M_3 was used fall within the groups of low and intermediate values of the coefficient of friction, while 79 percent of the tests in which movement M_2 was used fall within the groups of high and intermediate values of the coefficient of friction. Those tests in which movement M_1 was used are equally divided between the groups of low and intermediate and high and intermediate values of the coefficient of friction, being 64 percent in both cases.

TABLE 7.—*Classification of values of coefficient of friction for the various directions of movement*

Values of coefficient of friction (*k*)	Percentage of tests using each direction of movement		
	M_2	M_1	M_3
	Percent	*Percent*	*Percent*
High	57	36	7
Intermediate	22	28	50
Low	21	36	43

Symbols used are:
M_1 = Direction of movement and finish of plates parallel.
M_2 = Direction of finish of plates parallel, direction of movement normal to direction of finish.
M_3 = Direction of finish of plates at right angles.

In the same 14 groups of tests seizure was noted as follows: For movement M_2, 11 groups or 79 percent seized; for movement M_3, 9 groups or 64 percent seized; for movement M_1, 7 groups or 50 percent seized. The combinations of like ferrous materials seized in all tests while the combinations of like bronzes seized in only 9 out of 24 tests or in 38 percent.

If the bronze and ferrous materials are considered separately, table 6 gives the following indications for bronzes:

For finish P_C movement M_3 is best and movement M_1 ranks second.

For finish P_M movement M_1 is best with movement M_3 ranking second.

For finish P_F movement M_2 is best with movements M_1 and M_3 rating equally for second place.

For finish M movement M_1 is best with movement M_3 second, with but slight differences between the two.

This tabulation shows, as has already been concluded from table 5, that for bronzes in combination the milled or medium-planed finishes give the lowest coefficients of friction. For these finishes, direction of movement M_1 is most satisfactory, although in general there is not a great difference between the coefficients for M_1 and M_3.

For ferrous materials, table 6 indicates that, considering all finishes, direction of movement M_3 is superior to M_1 and M_2, since it gives the lowest values in 4 out of 6 groups. However, in the case of the milled finish, the difference between M_3 and M_2 is not significant.

It is apparent from table 6 that, in the two groups of tests with rolled or planished finishes, direction of movement had no pronounced effect, as both high and low values of the coefficients of friction were evenly divided between movements M_2 and M_3 and seizure was noted in both the high and low groups. No seizure was noted for movement M_1.

If one finish and one direction of movement were to be selected for all combinations of metals, the one that would probably be most generally satisfactory would be the milled finish with the finishing cuts at right angles (M_3).

COMBINATIONS OF LIKE OR UNLIKE FERROUS MATERIALS HAD HIGHEST COEFFICIENTS OF FRICTION

In the 190 tests made, only 31 (exclusive of 2 tests with rusted cast iron) showed evidence of wear, the loss in thickness varying from 0.0005 to 0.0020 of an inch. Of the 31 tests showing wear, 22 were of like materials (10 bronzes and 12 ferrous materials) and 9 were of unlike materials (4 bronzes in combination with ferrous materials and 5 combinations of unlike ferrous

Table 8.—*Effect of materials on the magnitude of the coefficient of friction (111 unlubricated sets considered)*

ination of materials used	Number of sets tested	Group no. 1—37 lowest values of k [1]				Group no. 2—37 intermediate values of k				Group no. 3—37 highest values of k			
		Number of sets	Percentage of sets tested	Number of sets showing seizure	Number of sets showing wear	Number of sets	Percentage of sets tested	Number of sets showing seizure	Number of sets showing wear	Number of sets	Percentage of sets tested	Number of sets showing seizure	Number of sets showing wear
e and ferrous	22	18	81.8		[illegible]	3	13.6		1	[illegible]	4.6		
e bronzes	7	5	71.4			2	28.6						
ronzes	47	14	29.8	2	[illegible]	25	53.2	8	1	8	17.0	8	
e ferrous	13					2	15.4	2		11	84.6	10	4
errous	22					3	12.7	[illegible]		17	77.3	17	[illegible]
Total	111	37		2	[illegible]	37		12	[illegible]	[illegible]		35	[illegible]

[1] k=Coefficient of friction.

erials); 9 were lubricated and 22 were unlubricated. nty seized during testing and 11 did not seize.

h 20 cases wear was evident where a coarse-planed h (P_C) was used, in 3 cases where a medium-planed h (P_M) was used, in 5 cases where a fine-planed h (P_F) was used, and in 3 cases where a milled h (M) was used.

ear occurred in 20 cases where the direction of ement and the directions of finish of both plates parallel (M_1), in 6 cases where the directions of h were parallel and the direction of movement was nal thereto (M_2), and in 5 cases where the direc- s of finish of the plates were at right angles (M_3).

venteen of the combinations showing wear con- d of ferrous materials, 10 combinations consisted ronzes, and 4 combinations consisted of bronze ferrous materials. In three cases, where unequal occurred in the two plates of a combination of ze and ferrous metal, the ferrous materials showed greater wear.

reaching any conclusion with respect to the im- ance of wear as disclosed by these tests, con- ation should be given to the fact that the wear rved took place during only 1,200 slips of the test s and that this number of movements represents a very limited part of the total number to which ing plates may be subjected during their useful Measurable wear occurred in only a small per- age of the total number of tests, and in the ma- y of the cases where it did occur, either a coarse- ed finish, which would not be recommended in any , or a finish or direction of movement unsuited to particular combinations of metals involved was . Therefore, it seems probable that when a proper tion of materials and surface finishes is made, wear be expected to be negligible.

nce the use of a lubricant appeared to be of doubt- alue in permanently decreasing the coefficients for n materials, and furthermore, since tests of lubri- l combinations were not made in all cases, only 111 tests of unlubricated plates listed in table 3 s of rusted plates excluded) were considered in rmining the relative merits of the materials tested se in bridge bearing plates.

y arranging these 111 tests in the order of increasing icients of friction and dividing them into three ps of 37 tests each, the results shown in table 8 obtained. These clearly indicate that combina- s of bronze and ferrous materials and of unlike zes in combination are the most efficient, as 18 out total of 22, or 82 percent, and 5 out of 7, or 71 ent, respectively, of the total number of tests made of these two classes of combinations fall within the group having the lowest coefficients of friction (group 1, table 8). Moreover, these two classes of combinations comprise 23 out of a total of 37, or 62 percent of the total tests falling in group 1.

In group 1, seizure was noted in only two combinations and was small in amount. These were like bronzes, both with a rolled finish, and seizure occurred in only 7 and 12 percent, respectively, of the total number of slips under any load intensity.

Group 3 of table 8 indicates that the combinations of unlike or of like ferrous materials are the most unsatisfactory of all of those tested, as 11 out of 13, or 85 percent, and 17 out of 22, or 77 percent, respectively, of the total number of tests made of these combinations fall within the group of the highest values of the coefficient of friction. These two classes of combinations comprise 28 out of 37, or 76 percent, of the tests falling within this group. Seizure was noted in all of the tests made of these two classes of combinations with the single exception of one combination of unlike ferrous materials.

It will be noted by reference to the general compilation of results (table 3) that the high lead bronzes in combination with like materials, or in combination with phosphor bronze or stainless steel, rank among the most satisfactory. The high lead bronze in combination with stainless steel shows next to the lowest coefficient of friction (0.110) of the 111 unlubricated combinations tested. The high lead bronzes in combination with like materials or in combination with phosphor bronze fall within the 13 lowest coefficients of friction of the 111 unlubricated combinations tested, with coefficients ranging from 0.128 to 0.132 as compared to the mean coefficient, 0.137, of group 1, table 3. This group comprises the 37 lowest coefficients of the 111 tests made of unlubricated plates.

EXPOSURE TO CALCIUM CHLORIDE HAD LITTLE EFFECT ON PLATES

Since the tests in this investigation indicated that combinations of ferrous materials and bronzes produced the lowest coefficients of friction and also indicated that rust may result in a substantial increase in the coefficient of friction, the use of stainless steel suggested itself because of its nonrusting properties. However, doubt existed as to the possible electrolytic action which might result from its use in combination with bronze when exposed to salt air. For the above reasons, a limited series of exposure tests was made in an attempt to obtain indications of electroyltic action, if such existed.

The procedure adopted was as follows: Eight samples of cast bronze, four of grade A and four of grade B,

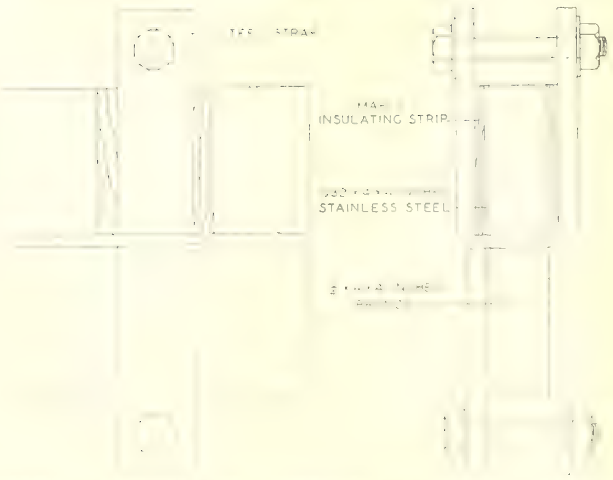


FIGURE 8.—ASSEMBLY OF PLATES FOR TESTS TO DETERMINE ELECTROLYTIC ACTION.

with machined surfaces, were used in combination with thin plates of stainless steel 0.032 inch thick with cold-rolled surfaces as furnished by the manufacturer. These eight combinations of bronze and steel were clamped together by means of straps of iron or soft steel 1 inch wide bolted around the centers of the 4-inch square specimens used. In four sets of specimens the clamps were in direct contact with the specimens, thus forming a direct metallic or uninsulated bond between the two plates. In the other four sets of specimens thin strips of maple were placed between the clamps and specimens as insulation. The methods of clamping the specimens together and of insulating them are shown in figure 8.

One insulated and one uninsulated set of specimens were subjected to calcium chloride vapor by suspending them in the top of a brine tank of a cold storage plant. One insulated and one uninsulated set of specimens were subjected to a vapor of sodium chloride by suspending them over a saturated solution of this salt through which a small amount of air was continually passing, the top of the container being covered with canvas.

One set each of insulated and uninsulated specimens were immersed in saturated solutions both of calcium chloride and of sodium chloride. All specimens were left in place for 4 months. They were then removed, rinsed in hot water and dried with paper towels. All of the specimens were measured with micrometer calipers before and after exposure.

The four specimens exposed to calcium chloride either in vapor or immersed in the solution will be considered first (figs. 9 and 10). In no case was any apparent effect of exposure present on the contact faces of either the stainless steel or the bronzes. The outer face of the stainless steel immersed with no insulation between the specimens and the iron clamps showed a slight deposit of copper except where covered with the clamps. None of the other three stainless steel specimens showed any effect on the outer faces. Three of the four bronze specimens showed discoloration of the outer surfaces except where the surfaces were covered with either the clamps or the insulation strips. In no case was there any apparent breaking down of the surface or any measurable change in thickness of either the bronze o steel specimens.

EXPOSURE TO SODIUM CHLORIDE NOT DETRIMENTAL TO PLATE

In the case of the four specimens exposed to sodiu chloride vapor or immersed in the solution, the follow ing effects were noted (figs. 11 and 12).

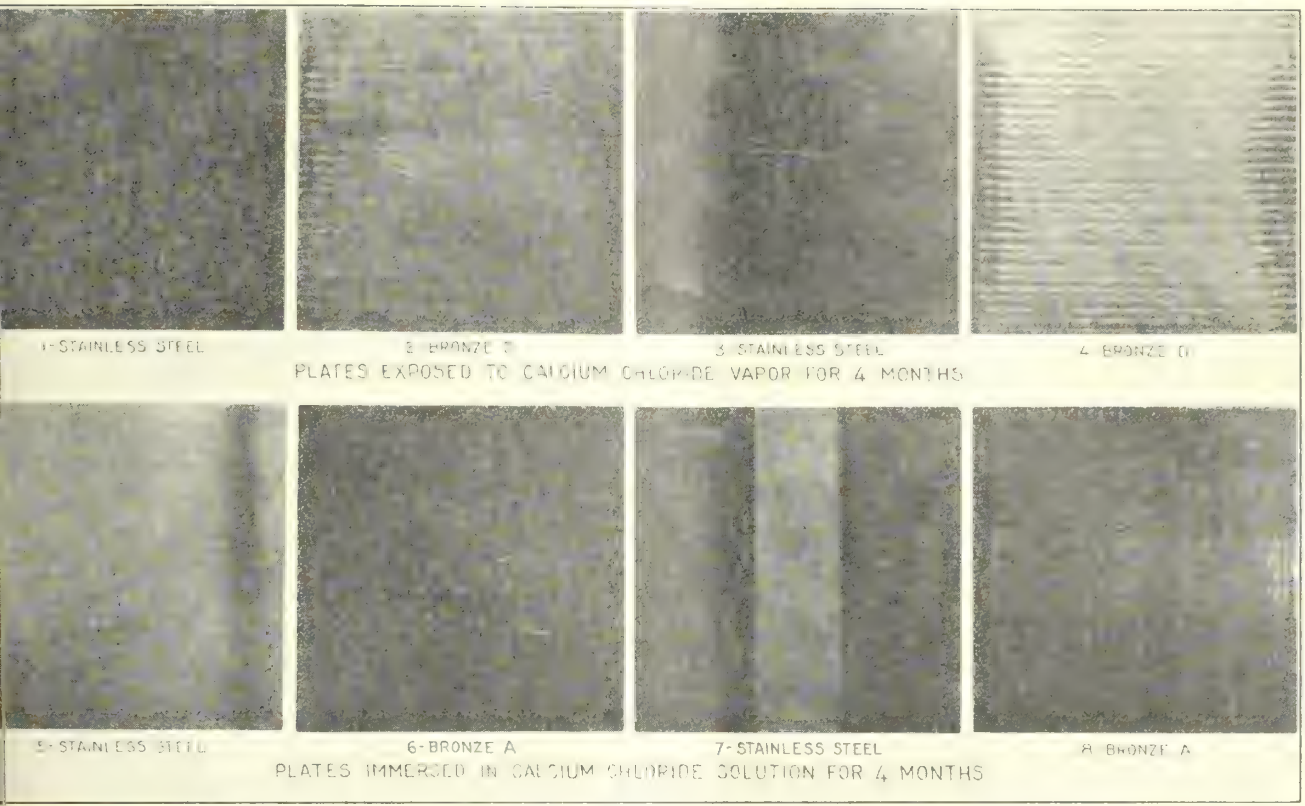
The two steel specimens that were immersed showe no effect of immersion on the contact faces. The con tact face of one bronze specimen showed no effect immersion, while the other bronze specimen showed on small discolored spot where the contact between th steel and bronze was poor. One of the outer faces the steel specimens showed no effect of immersion, whil the other specimen was discolored in spots where sal crystals had formed. The outer faces of both bronz specimens were slightly discolored by immersion excep where the surface was covered by the clamps or insula tion strips.

The contact faces of both the two steel specimen and the two bronze specimens that were exposed t vapor showed discoloration in spots where contact be tween the steel and the bronze was poor. Both sets specimens showed two bright spots on both the ste and the bronze where the contact between the bearin faces was good. The outer face of one steel specim was discolored where it was in contact with the blac iron clamps, while the other was discolored in two spot adjacent to the clamps. The outer faces of both bronz specimens exposed to vapor were discolored and on specimen showed two spots of corrosion adjacent to th iron clamps with a resulting increase in roughness of th surface.

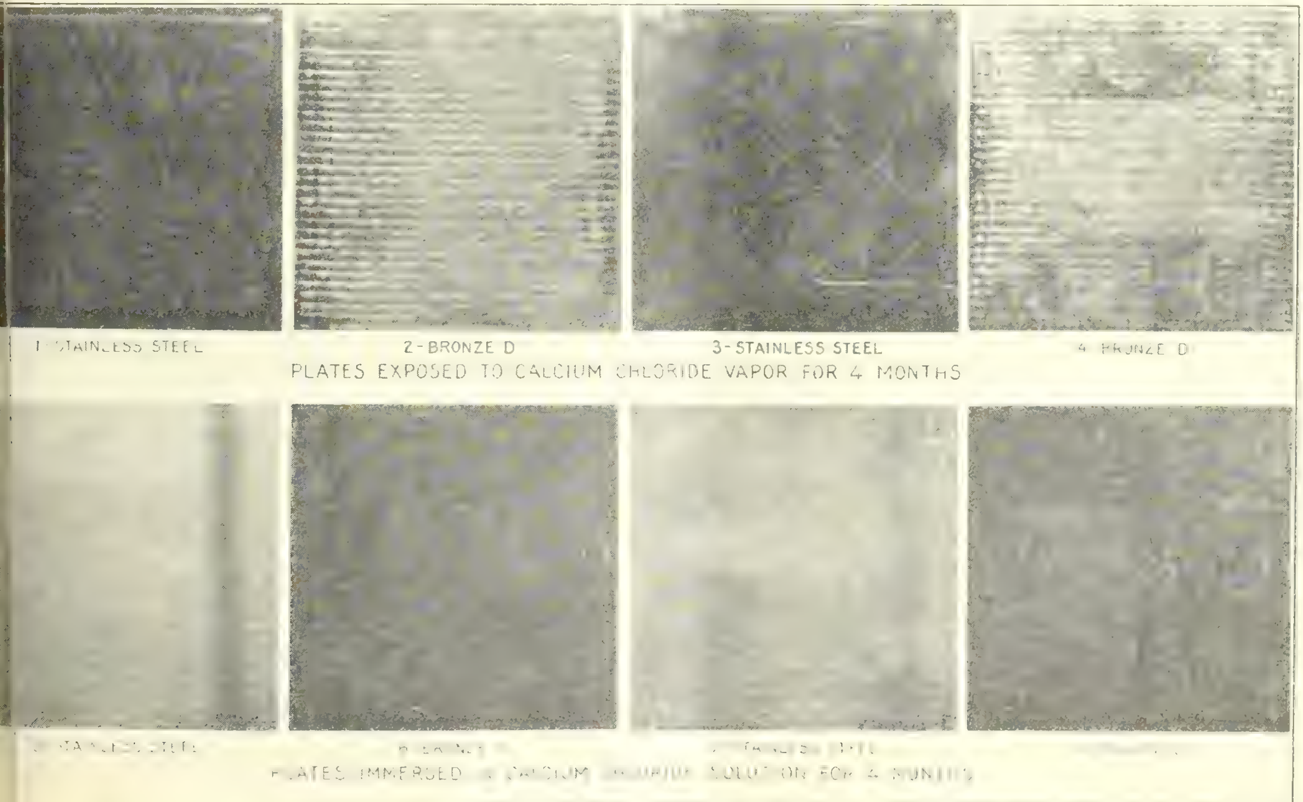
No measurable change in thickness was found in an of the specimens and in only the one bronze specime where corrosion was found was any apparent break-dow of the surface noted. Figures 9 to 12 show both conta and outer faces after the exposure tests were complete Differences in texture, color, and surface finish, with th resulting variations in the reflection of light, present a difficult problem to the photographer. As a resul these photographs may give an exaggerated idea of th conditions of the various surfaces. However, they gi a fair idea of the relative results of the various exp sures.

Examination of these plates for evidences of electr lytic action revealed that only one of the eight sets specimens gave indications of such action. When bron A, in combination with stainless steel, was immerse in a solution of calcium chloride with no insulation be tween the iron clamps and the test specimens (i. e with a direct metallic connection between the unlik materials), a deposit of copper was found on the oute surface of the steel except where it was covered by th clamp (fig. 9, no. 7). The outer surface of the bronz also showed an increase of copper on the surface

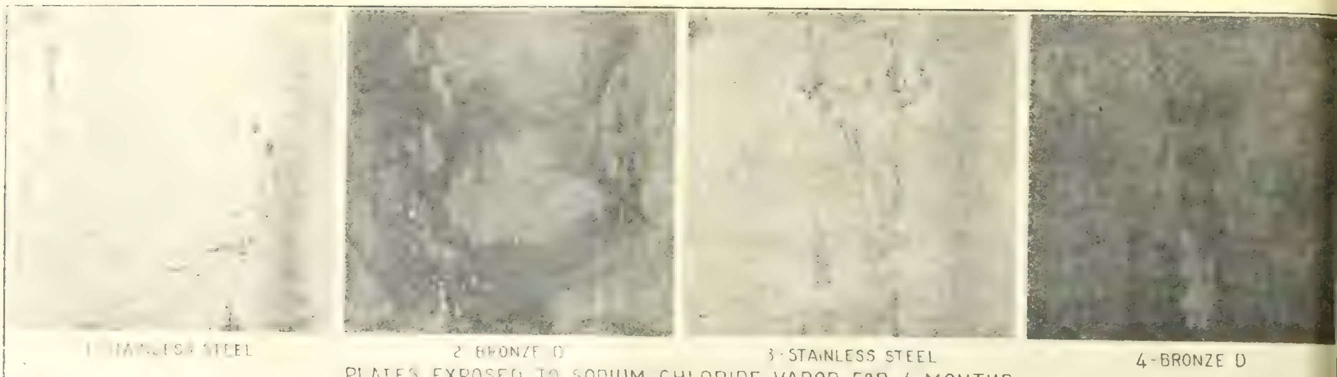
In none of the eight sets of specimens were effects electrolysis evident on the contact faces of the spec mens although in three of the bronze specimens an two of the steel specimens these faces were discolore in spots where contact between the two surfaces w imperfect. Due consideration should be given to th fact that the stainless steel plates used in these tes were only 0.032 inch thick and consequently we


1-STAINLESS STEEL
2-BRONZE D
3-STAINLESS STEEL
4-BRONZE D
PLATES EXPOSED TO CALCIUM CHLORIDE VAPOR FOR 4 MONTHS
5-STAINLESS STEEL
6-BRONZE A
7-STAINLESS STEEL
8-BRONZE A
PLATES IMMERSED IN CALCIUM CHLORIDE SOLUTION FOR 4 MONTHS

e 9.—Appearance of Bronze and Stainless Steel Bearing Plates After Immersion in and Exposure to Calcium hloride. There Was No Insulation Between Clamps and Plates. Nos. 1, 2, 5, and 6 Were Contact Faces, and os. 3, 4, 7, and 8 Were Outer Faces of Plates.

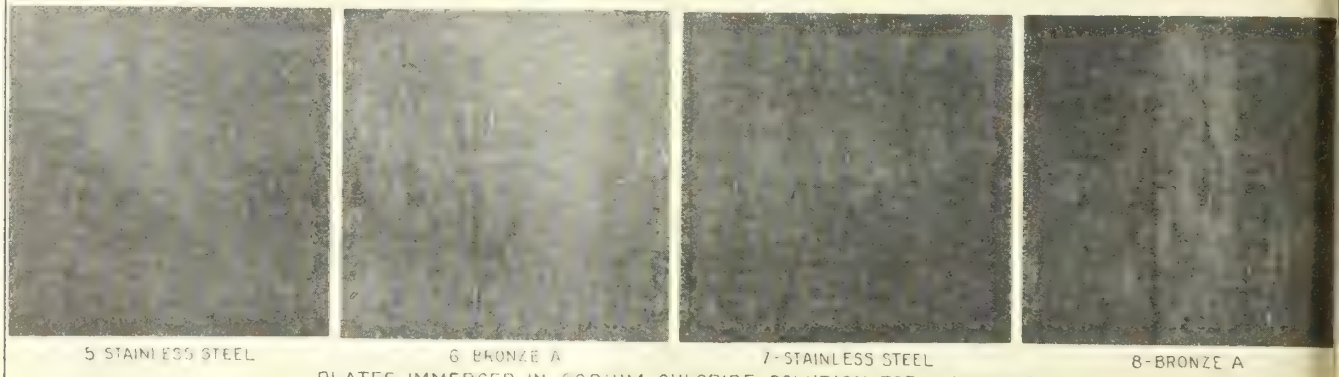

1-STAINLESS STEEL
2-BRONZE D
3-STAINLESS STEEL
4-BRONZE D
PLATES EXPOSED TO CALCIUM CHLORIDE VAPOR FOR 4 MONTHS
5-STAINLESS STEEL
7-STAINLESS STEEL
PLATES IMMERSED IN CALCIUM CHLORIDE SOLUTION FOR 4 MONTHS

10.—Appearances of Bronze and Stainless Steel Bearing Plates After Immersion in and Exposure to Calcium Cloride. Strips of Wood Insulated the Iron Clamps From the Plates. Nos. 1, 2, 5, and 6 Were Contact Faces, ad Nos. 3, 4, 7, and 8 Were Outer Faces of Plates.



1-STAINLESS STEEL 2-BRONZE D 3-STAINLESS STEEL 4-BRONZE D

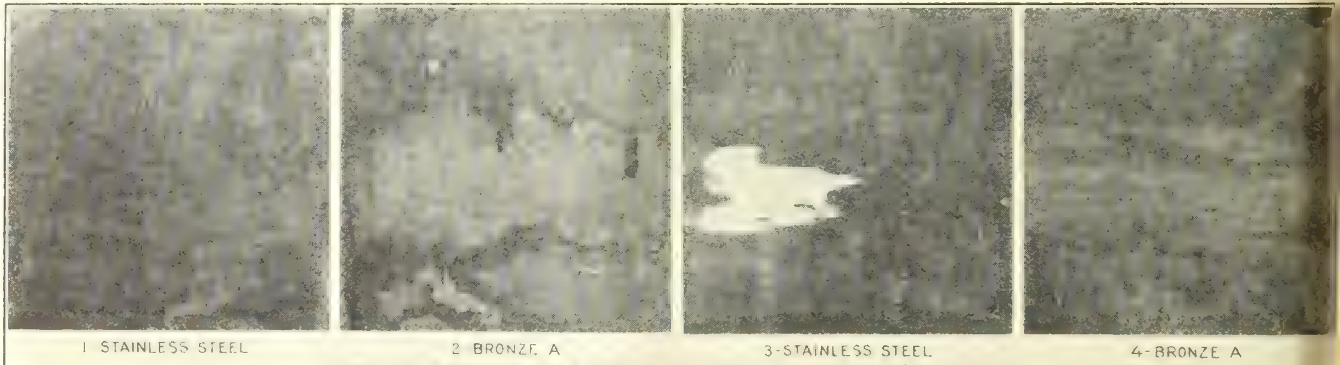
PLATES EXPOSED TO SODIUM CHLORIDE VAPOR FOR 4 MONTHS



5-STAINLESS STEEL 6-BRONZE A 7-STAINLESS STEEL 8-BRONZE A

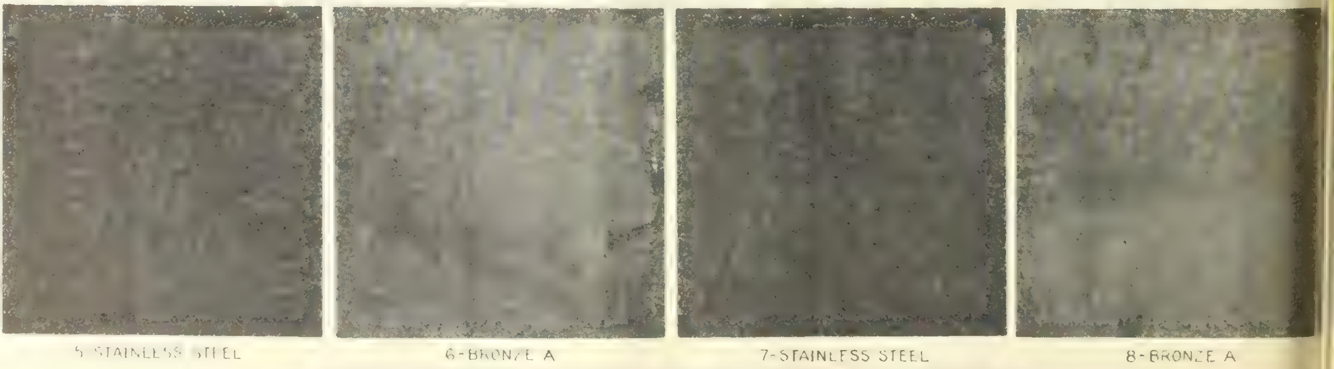
PLATES IMMERSED IN SODIUM CHLORIDE SOLUTION FOR 4 MONTHS

Figure 11.—Appearances of Bronze and Stainless Steel Bearing Plates After Immersion in and Exposure to Sodiu Chloride. There Was No Insulation Between Clamps and Plates. Nos. 1, 2, 5, and 6 Were Contact Faces, an Nos. 3, 4, 7, and 8 Were Outer Faces of Plates.



1-STAINLESS STEEL 2-BRONZE A 3-STAINLESS STEEL 4-BRONZE A

PLATES EXPOSED TO SODIUM CHLORIDE VAPOR FOR 4 MONTHS



5-STAINLESS STEEL 6-BRONZE A 7-STAINLESS STEEL 8-BRONZE A

PLATES IMMERSED IN SODIUM CHLORIDE SOLUTION FOR 4 MONTHS

Figure 12.—Appearances of Bronze and Stainless Steel Bearing Plates After Immersion in and Exposure to Sod Chloride. Strips of Wood Insulated the Iron Clamps From the Plates. Nos. 1, 2, 5, and 6 Were Contact Fa and Nos. 3, 4, 7, and 8 Were Outer Faces of Plates.

somewhat flexible. Moreover, they were clamped to the bronze specimens by clamps only 1 inch in width passing over the center of the specimens. As a result any slight unevenness, caused by shearing of the thin-steel plates or by marking with an identification number, caused faulty contact between the plates and allowed vapor or moisture to penetrate and settle. It is believed that, where thicker plates are used and are subjected to pressures usually existing on bridge bearing plates, contact between the surfaces will be such as to prevent penetration by either moisture or vapor. Four of the eight outer surfaces of the steel showed no effect, one showed the copper deposit mentioned above, and three were discolored in spots adjacent to the clamps undoubtedly resulting from the breaking down of the black iron of the clamps. No evidence of any break-down of the surface was apparent.

The outer surfaces of the bronze specimens showed the normal discoloration to be expected when finished metal is exposed to salt air, and in one specimen two small spots of corrosion with a slight increase in roughness were found adjacent to the iron clamps. The iron clamps all showed pitted and rusted surfaces as a result of exposure.

These tests would seem to indicate that for normal exposure to salt air no electrolytic action or breaking down of contact faces may be expected when bronze and stainless steel are used in combination if the contact between the plates is good.

CONCLUSIONS

1. The coefficient of friction for bearing plates remains constant under varying loads for any combination of materials tested.

2. An initial application of graphite grease or other lubricant that will flow appears to be of doubtful value in permanently reducing the coefficients of friction when used under conditions such as obtained in these tests.

3. In general, for the materials tested the relative coefficients of friction, in increasing order of magnitude, are as follows:

a. Ferrous materials in combination with bronzes.
b. Hard bronzes in combination with softer bronzes.
c. Like bronzes in combination.
d. Ferrous materials in combination with like or unlike ferrous materials.
e. Ferrous materials in combination where subject to rust.

4. The following are indicated as the most satisfactory finishes for various combinations of materials:

a. Ferrous materials in combination—a milled finish.
b. Like bronzes in combination—a milled or medium-planed finish.
c. Ferrous materials and bronzes in combination—a milled or fine-planed surface.
d. A cold-rolled finish on bronze compares favorably with machined finishes provided the plates are rolled to a surface which will give uniform contact.

5. The directions of movement most satisfactory for machined plates are with finishing cuts at right angles (M_3) and with direction of movement and direction of finishing cuts parallel (M_1), with M_3 showing a slight superiority. With rolled or planished finishes, but slight variations in friction are caused by the direction of movement, although less seizure is noted when the direction of movement and the direction of finish are parallel.

6. Wear is probably a negligible factor when suitable materials and finishes are used.

7. The limited exposure tests made do not indicate that destructive corrosive action may be expected from the use of combinations of bronze and stainless steel when exposed to salt air.

8. If proper care is used in selecting materials and finishes, a coefficient of friction varying from 0.10 to 0.15 may be expected, with variations of 5 percent above and below mean values, for load intensities of the order of 250 to 1,000 pounds per square inch.

DISPOSITION OF STATE MOTOR-

[Compiled from reports

State	[illegible]	Adjustment for undistributed balances, etc.	Net total funds distributed	Expense of collection and administration	For other administrative purposes	For State highway purposes						
						Construction, maintenance, and administration [3]	State highway police	Service of State highway obligations				Total for State highway purposes
								State highway bonds	State-assumed local obligations [4]	Notes and other short-term loans	Total	
Alabama	$10,313,112	−$3,068	$10,310,044	$20,298	$43,691	$3,735,071	$39,300	$1,355,498			$1,355,498	$5,129,869
Arizona	3,278,598		3,278,598	39,946		1,981,576	82,938					2,064,514
Arkansas	8,261,907	−15,798	8,246,109	304,157	68,118	1,400,390		2,748,773	$3,059,506	$70,396	5,878,675	7,279,065
California	39,983,955	−2,365,667	37,618,288	132,687		24,793,382						24,793,382
Colorado	6,009,533	−439	6,009,094	98,154		4,243,132	73,128					4,316,260
Connecticut	5,671,844	−159,224	5,512,620	41,000		5,471,620						5,471,620
Delaware	1,481,819	[11] 228,563	1,710,382	6,076		1,049,105	96,621	52,748	277,269		330,017	1,475,743
Florida	17,896,972	−10,813	17,886,159	20,427		7,581,351	58,957		2,552,247		2,552,247	10,192,555
Georgia	15,771,723		15,771,723	472,181		7,496,569						7,496,569
Idaho	3,124,297	−5,325	3,118,972	16,292		2,901,555		207,125			207,125	3,108,680
Illinois	30,385,482	28,614	30,414,096	142,507	178,002	9,566,502						9,566,502
Indiana	19,262,319		19,262,319	81,657	67,056	9,391,090						9,391,090
Iowa	11,549,118	5,000	11,554,118	92,118		3,060,253			3,309,747		3,309,747	6,370,000
Kansas	8,961,190	33,289	8,994,479	295,766	86,500	5,356,573	66,618		693,266		693,266	6,116,457
Kentucky	9,835,918	31,398	9,867,316	48,507		9,794,488	24,321					9,818,809
Louisiana	9,416,969	578,665	9,995,634	62,000				8,064,450			8,064,450	8,064,450
Maine	4,572,827	−1,058	4,571,769	14,872		2,611,947	148,448	1,253,086			1,253,086	4,013,481
Maryland	8,278,025		8,278,025	51,331		2,976,166		1,380,548			1,380,548	4,356,714
Massachusetts	17,334,090	2,824	17,336,914	50,000		3,764,015	200,792	441,930		15,445	457,375	4,422,182
Michigan	22,790,561	−23,476	22,767,085	120,945		12,465,565		4,082,060			4,082,060	16,547,625
Minnesota	11,362,258	−35,584	11,326,674	166,656		7,267,351	127,937					7,395,288
Mississippi	7,512,370	−3,242	7,509,128	26,858	70,000	4,268,447	26,349					4,294,796
Missouri	9,845,991	64,699	9,910,690	19,731	105,585	5,470,283	139,189	4,145,372			4,145,372	9,754,844
Montana	3,844,542	78,764	3,923,306	18,631		3,100,035		804,640			804,640	3,904,675
Nebraska	9,808,734	−7,028	9,801,706	95,514		5,370,609						5,370,609
Nevada	962,049		962,049	1,959		928,972	16,846		14,272		14,272	960,090
New Hampshire	2,868,166	4,360	2,872,526	4,150		1,970,753		726,895			726,895	2,697,648
New Jersey	18,205,102	−1,387,702	16,817,400	84,959		475,764		7,597,651			7,597,651	8,073,415
New Mexico	2,877,605		2,877,605	62,325		1,301,584		1,513,696			1,513,696	2,815,280
New York [2]	56,311,245	166,865	56,478,110	92,714		5,024,734	483,436	3,675,900			3,675,900	9,184,070
North Carolina	19,147,015	17,533	19,164,548	6,199	24,995	5,760,418	179,618	6,602,269	399,196		7,001,465	12,941,501
North Dakota	2,323,387	−2,611	2,320,776	25,000		1,523,041	6,959					1,530,000
Ohio	39,169,151	−1,354,539	37,814,612	187,440		15,654,932	354,386					16,009,318
Oklahoma	11,877,151	−324,787	11,552,364	237,543		4,911,832						4,911,832
Oregon	7,942,853	−99,525	7,843,328	26,129		3,649,210	198,473	2,805,233			2,805,233	6,652,916
Pennsylvania	10,651,831	493,817	11,145,648	209,677		22,723,714	793,531	3,322,949			3,322,949	26,840,194
Rhode Island	2,106,204	58,359	2,164,563	16,973		1,544,353		301,876			301,876	1,846,229
South Carolina	8,765,749	−66,777	8,698,972	[29] 38,500	9,500	3,522,026		1,117,962	2,524,151	544	3,642,657	7,164,683
South Dakota	4,315,419	24,079	4,339,498	14,410		1,877,967						1,877,967
Tennessee	14,966,016	234,778	15,200,794	150,594		2,103,571		50,356	2,133,833	4,095,377	6,279,566	8,383,137
Texas	33,606,085	−86,806	33,519,279	335,345		16,603,812			8,290,061		8,290,061	24,893,873
Utah	2,714,341	−29,341	2,685,000	8,000		2,577,183	99,817					2,677,000
Vermont	2,048,645	219,677	2,268,322	2,200		1,218,366	34,560	447,445			447,445	1,700,371
Virginia	13,340,505	−147,169	13,193,336	164,100	28,885	6,351,567		476,210			476,210	6,827,777
Washington	12,568,379		12,568,379	22,684		4,036,904		[34] 97,930			97,930	4,134,834
West Virginia	6,102,941	−1,741	6,101,200	23,468		1,603,058		4,233,429			4,233,429	5,836,487
Wisconsin	16,249,747	−825,947	15,423,800	52,421	178,540	6,286,279			2,277,229		2,277,229	8,563,508
Wyoming	1,931,912	90,403	2,022,315	11,051		1,269,578	32,479	112,000			112,000	1,414,057
District of Columbia	2,197,209	374,793	2,572,002									
Total	619,802,062	−4,221,087	615,580,975	4,275,369	860,872	258,036,693	3,284,705	57,618,031	25,530,777	4,181,762	87,330,570	348,651,966

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[1] Amounts distributed during the calendar year differ in many cases from actual collections because of undistributed balances and lag between accounts of collecting and expending agencies. Adjustments also include deduction of receipts not classed as highway-user imposts as follows: Proceeds of tax on gasoline used in aviation in Idaho, Maine, Michigan, Nebraska, Oregon, and Wyoming, and proceeds of tax on nonmotor-vehicle fuel in Ohio.

[2] In many States the proceeds of motor-fuel taxes, motor-vehicle fees, and motor-carrier taxes are placed in a common fund from which the distribution is made. In these cases the amounts distributed have been prorated in proportion to the receipts, not otherwise dedicated, from these three sources of revenue. See following tables.

[3] Where reported separately from collection expenses, funds allotted for motor-fuel inspection, administration of motor-vehicle department, and regulation of motor vehicles are shown in this column.

Includes funds allotted for expenditure on urban extensions of State highway systems where reported separately from other funds distributed for local roads and streets.

Payments on local obligations assumed by States as reimbursement for local roads added to State system.

In States indicated by star (*) law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts were not reported separately.

In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately. See note 4.

To State general funds unless otherwise noted. Allocations to county or municipal general funds may have been used in part for highways, but such amounts not reported.

For engineering expenses in connection with irrigation.

[illegible]

[illegible] transferred to general fund as result of refunding operation which replaced [illegible] fund bonds with serial bonds.

To Division of Airways, $15,616; Dade Memorial Park, $818.

For Confederate pensions and past-due teachers' salaries, $1,786,840; prison camps, $2,968.

To port of New Orleans and Lake Charles Harbor for harbor improvement.

To Conservation Department for oyster propagation, $75,000; Chesapeake Bay ferry companies, $48,727.

[illegible] debt service on nonhighway portion of emergency public works loan.

FUEL TAX RECEIPTS, 1935

of State authorities]

For local roads and streets				For other highway purposes (parks and forest roads, etc.)	For nonhighway purposes					
For work on county and local roads	For work on city streets	Service of local highway obligations	Total		[illegible]	For relief of unemployment or destitution	For education	For other purposes	Total	
$5,107,186			$5,107,186							Alabama.
983,365			983,365			$186,667		[illegible]	$190,773	Arizona.
512,731		81,738	594,469							Arkansas.
*12,510,058	$182,161		12,692,219							California.
[10] 1,594,700			1,594,700							Colorado.
										Connecticut.
					228,563				228,563	Delaware.
		5,104,495	5,104,495		[illegible]			[illegible]	2,568,682	Florida.
2,5[illegible]			[illegible]		860,675		$2,615,477	[illegible]	[illegible]	Georgia.
										Idaho.
[illegible]	*6,596,8[illegible]		13,166,075		141,269	3,512,788	[illegible]		7,361,010	Illinois.
7,512,872	1,878,218		9,391,090		[illegible]				331,426	Indiana.
5,092,000			5,092,000							Iowa.
2,495,756			2,495,756							Kansas.
										Kentucky.
							[illegible]	[illegible]	[illegible]	Louisiana.
543,416			543,416							Maine.
779,019	2,312,168	642,106	3,733,293		12,960				[illegible]	Maryland.
2,372,739			2,372,739	[illegible]	9,500,000	453,789			9,953,789	Massachusetts.
*6,094,185			6,094,185		[illegible]				1,330	Michigan.
*[illegible]			[illegible]		[illegible]				[illegible]	Minnesota.
*3,117,474			3,117,474							Mississippi.
										Missouri.
										Montana.
*2,901,185	321,180		3,222,365			1,113,218			1,113,218	Nebraska.
										Nevada.
		170,728	170,728							New Hampshire.
2,765,678		192,763	2,958,441			3,964,062	1,332,[illegible]	[illegible]	[illegible]	New Jersey.
										New Mexico.
*8,090,771			8,090,771		[illegible]				39,110,555	New York.
[22] 4,712,527			4,712,527		1,479,326				[illegible]	North Carolina.
765,000			765,000		[illegible]				[illegible]	North Dakota.
7,205,400	4,929,445		12,134,845				9,487,[illegible]		[illegible]	Ohio.
*2,908,983			2,908,983		[illegible]			[illegible]	3,494,006	Oklahoma.
*1,144,003			1,144,003	20,280						Oregon.
*8,345,374	579,361		8,924,735	[illegible]		5,086,269		[illegible]	5,124,475	Pennsylvania.
						301,361			301,361	Rhode Island.
*1,352,684			1,352,684		[illegible]				133,605	South Carolina.
				60,[illegible]	[illegible]			242,176	2,356,601	South Dakota.
4,232,978			4,232,978			104,8[illegible]		[illegible]	[illegible]	Tennessee.
							8,290,061		8,290,061	Texas.
										Utah.
565,751			565,751							Vermont.
6,170,790			6,170,790					[illegible]	1,724	Virginia.
*6,511,680	994,320	[34] 79,574	7,585,574			825,287			825,287	Washington.
[illegible]			[illegible]							West Virginia.
3,389,383	489,436		3,878,819	109,614	[illegible]				[illegible]	Wisconsin.
597,207			597,207							Wyoming.
	2,572,002		2,572,002							District of Columbia.
123,420,040	20,855,123	6,271,404	150,546,567	775,185	57,184,330	15,548,262	26,363,586	11,374,838	110,471,016	Total.[37]

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[17] Pro-rata share service of highway relief bonds, a State obligation incurred for improvement of local roads.
[18] Includes $767,240, pro-rata share of temporary loan to general fund for relief.
[19] For service of institutional construction bonds, $434,468; Department of Commerce and Navigation, $90,000; less credit for excess allocations in 1934, (−) $120,445.
[20] Appropriations out of general fund for highway purposes have been credited against payments of motor-fuel tax and motor-vehicle fees to the State general fund and prorated in proportion to net receipts not otherwise dedicated.
[21] To State general fund after crediting appropriations for highway purposes, $37,614,987; New York City general fund, $1,495,568.
[22] For county roads under State control.
[23] In cities situated on State highways one-sixth municipal allotment to be used on urban extensions of State system.
[24] For service of general State debt.
[25] Differs from total in a previous table issued by the Bureau—State motor-fuel tax receipts, 1935—by amount of refunds, $57,009, reported subsequent to issuance of previous table.
[26] In computing adjustment, amounts loaned to general fund for relief purposes in 1934 and 1935 (pro-rata share, $3,622,384) have been included in the undistributed balances.
[27] For aircraft landing fields, $25,824; cooperative work other departments, $12,382.
[28] Differs from total in a previous table issued by the Bureau—State motor-fuel tax receipts, 1935—by amount of inspection fees, $181,605, reported subsequent to issuance of previous table.
[29] Amount shown as payment to general fund represents proceeds of inspection fees paid to general revenue, $181,605, less estimated cost of tax collection and inspection, as given above.
[30] For payments on real-estate bonds.
[31] Service of general fund bonds, $2,116,489; Great Smoky Mountain Park bonds, $211,649; aviation projects, $1,126.
[32] For county roads under State control in all but 3 counties, $5,944,322; transferred to remaining 3 counties, $226,468.
[33] For aviation purposes.
[34] Debt service charges on $10,000,000 emergency relief bond issue prorated in proportion to allotments for State highways, local roads, and nonhighway purpo
[35] Includes $500,000 to State general fund and $2,140,898 to towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles.
[36] Paid out of general revenue. Amount not reported.
[37] See notes 25 and 28.

DISPOSITION OF STATE MOTOR-

[Compiled from reports

State	Net total receipts of calendar year [1]	Adjustments due to undistributed balances, etc. [2]	Net total funds distributed [3]	Expenses of collection and administration [4]	For other administrative purposes [5]	For State highway purposes: Construction, maintenance, and administration [6]	For State highway purposes: State highway police	For State highway purposes: Service of State highway obligations: State highway bonds	For State highway purposes: Service of State highway obligations: State-assumed local obligations [7]	For State highway purposes: Service of State highway obligations: Notes and other short-term loans	For State highway purposes: Service of State highway obligations: Total	For State highway purposes: Total for State highway purposes
Alabama	$3,574,151	−$1,096	$3,573,055	$349,048		$2,064,145	$133,664	$373,015			$373,015	$2,570,824
Arizona	848,146	−15,266	832,880	149,466		654,658	27,400					682,058
Arkansas	2,529,191		2,529,191	75,484		455,460	86,280	894,005	$995,067	$22,895	1,911,967	2,453,707
California	10,562,502	−613,724	9,948,778	2,028,889		2,931,082	2,068,763					4,999,845
Colorado	2,206,930		2,206,930	311,620	$36,067	72,245						72,245
Connecticut	6,108,224		6,108,224	853,699		2,754,987	325,000					3,079,987
Delaware	1,072,079	332,606	1,404,685	46,654		728,974	67,138	36,652	192,661		229,313	1,025,425
Florida	4,954,774		4,954,774	375,204	174,211							
Georgia	1,248,278		1,248,278	165,024	45,577	754,723						754,723
Idaho	1,880,087	−84,258	1,795,829	57,685		168,325	53,065					221,390
Illinois	20,437,337	718	20,438,055	941,341	304,279	7,508,748	893,175	9,081,120	376,789		9,457,909	17,859,832
Indiana	8,154,293	−53,893	8,100,400	839,447		3,182,090	385,227					3,567,317
Iowa	10,314,046	−313,374	10,000,672	752,862		4,442,800			4,805,010		4,805,010	9,247,810
Kansas	3,495,576	−16,027	3,479,549	255,706		1,994,335	25,159		261,815		261,815	2,281,309
Kentucky	3,491,413	−13,823	3,477,590	385,599	32,099	2,528,753	15,132					2,543,885
Louisiana	3,563,380	−11,661	3,551,719	145,657		2,762,785	342,477	300,800			300,800	3,406,062
Maine	3,236,078	−1,366	3,234,712	104,556	12,836	1,786,802	101,552	857,221			857,221	2,745,575
Maryland	4,453,440	−259,198	4,194,242	246,726	38,405	1,543,461	260,699	1,140,598			1,140,598	2,944,758
Massachusetts	6,305,397		6,305,397	1,453,460	35,000	2,328,397	124,208	273,375		9,555	282,930	2,735,535
Michigan	17,601,108	133,288	17,734,396	1,177,833			250,000					250,000
Minnesota	7,215,403	250,274	7,465,677	417,663	361,246	2,469,424	43,472	2,122,000	1,962,820		4,084,820	6,597,716
Mississippi	1,740,856	459	1,741,315	89,309		181,307	1,157					182,464
Missouri	8,311,786		8,311,786	485,415		4,388,842	111,672	3,325,857			3,325,857	7,826,371
Montana	1,381,568	−37,729	1,343,839	90,967			72,540					72,540
Nebraska	1,999,405	8,154	2,007,559	77,421		575,191	12,500					587,691
Nevada	263,511	−17,496	246,015	22,163		153,548	2,742	67,562			67,562	223,852
New Hampshire	1,691,502	−4,150	1,687,352	102,943		1,327,734	136,700	4,953			4,953	1,469,387
New Jersey	16,623,763	−4,616,491	12,007,272	1,109,227		2,848,883						2,848,883
New Mexico	1,117,579	−13,934	1,103,645	127,564		439,237						439,237
New York	43,956,507	−280,983	43,675,524	2,345,572	98,071	6,919,284	665,714	5,061,880			5,061,880	12,646,878
North Carolina	6,636,748	632,900	7,269,648	322,043		2,177,914	67,910	2,496,203	150,929		2,647,132	4,892,956
North Dakota	1,422,695	−156,431	1,266,264	83,905	24,674	216,343	20,000					236,343
Ohio	21,535,578	127,825	21,663,403	1,321,331		4,815,160	109,002					4,924,162
Oklahoma	3,861,366	−43,073	3,818,293	287,156	256,616	1,284,205						1,284,205
Oregon	2,748,249	7,345	2,755,594	318,290		1,137,778	61,881	874,636			874,636	2,074,295
Pennsylvania	28,758,933	−1,782,890	26,976,043	1,391,596		21,137,536	738,140	3,090,998			3,090,998	24,966,674
Rhode Island	2,900,462	−1,494	2,898,968	259,468		2,269,111						2,269,111
South Carolina	1,791,050	−12,381	1,778,669	171,748		736,191	149,265	221,424	499,933	108	721,465	1,606,921
South Dakota	1,371,026	3,991	1,375,017	71,618		264,765						264,765
Tennessee	3,432,317	−33,989	3,398,328	214,089		2,751,490	190,922	66,476		35,488	101,964	3,044,376
Texas	15,745,897	−485	15,745,412	895,557		4,732,671	308,041					5,040,712
Utah	1,070,647	−233,382	837,265	99,765				737,500			737,500	737,500
Vermont	1,377,241	1,208,084	2,585,325	14,491		1,366,064	38,749	501,686			501,686	1,906,499
Virginia	5,150,755	9,741	5,160,496	312,404		4,479,035	194,960	173,469			173,469	4,847,464
Washington	3,495,253		3,495,253	341,161		2,635,070	507,098					3,142,168
West Virginia	4,820,637		4,820,637	48,459		1,125,795	29,277	2,973,051			2,973,051	4,128,123
Wisconsin	10,897,032	-326,651	10,570,381	661,541	35,000	4,199,529			1,538,492		1,538,492	5,738,021
Wyoming	482,893	−9,414	473,479	9,470		287,351	10,658	166,000			166,000	464,009
District of Columbia	910,226		910,226	99,172	63,493							
Total	318,747,713	−6,239,672	312,508,041	22,537,468	1,516,972	113,582,228	8,631,339	34,840,481	10,783,516	68,046	45,692,043	167,905,610

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[1] Amounts for many States differ from totals in a previous table issued by the Bureau—State motor-vehicle receipts, 1935—which gives receipts of the 1935 registration period.

[2] Amounts distributed during the calendar year differ in many cases from actual collections because of undistributed balances and lag between accounts of collecting and expending agencies.

[3] In many States the proceeds of motor-fuel taxes, motor-vehicle fees, and motor-carrier taxes are placed in a common fund from which the distribution is made. In these cases the amounts distributed have been prorated in proportion to the receipts, not otherwise dedicated, from these three sources of revenue. See tables that precede and follow this table.

[4] Collection expenses in many States include service charges deducted by county and local collectors.

[5] Where reported separately from collection expenses, funds allotted for collection of motor-fuel tax, payments to auto theft fund, and miscellaneous expenses of motor-vehicle regulation are shown in this column.

[6] Includes funds allotted for expenditure on urban extensions of State highway system, where reported separately from other funds distributed for local roads and streets.

[7] County or local obligations assumed by State as reimbursement for local roads added to State system.

[8] In States indicated by star (*) law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts so used not reported separately.

[9] In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately. See note 6.

[10] To State general funds unless otherwise noted. Allocations to county or municipal general funds may have been used in part for highways, but such amounts not reported.

[11] To county and municipal general funds.

[12] For engineering expenses in connection with irrigation.

[13] Funds allotted to counties for use on both State and local roads.

[14] Pro-rata share of State highway sinking fund transferred to general fund as a result of refunding operation which replaced sinking fund bonds with serial bonds.

[15] For Confederate pensions and past-due teachers' salaries, $190,755; prison camps, $317.

'EHICLE RECEIPTS, 1935

tate authorities]

For local roads and streets 8					For nonhighway purposes					
r work on unty and al roads 8	For work on city streets 9	Service of local highway obligations	Total	For other highway purposes (park and forest roads, etc.)	To general funds 10	For relief of unemployment or destitution	For education	For other purposes	Total	State
					11 $653,183				$653,183	Alabama.
								12 $1,356	1,356	Arizona.
										Arkansas.
2,920,044			$2,920,044							California.
13 802,721			802,721		730,476	$253,801			984,277	Colorado.
2,174,538			2,174,538							Connecticut.
					14 332,606				332,606	Delaware.
							$4,405,359		4,405,359	Florida.
					91,882			15 191,072	282,954	Georgia.
1,516,754			1,516,754							Idaho.
1,187,635			1,187,635		144,968				144,968	Illinois.
1,272,836	$318,209		1,591,045		2,102,591				2,102,591	Indiana.
										Iowa.
942,534			942,534							Kansas.
516,007			516,007							Kentucky.
										Louisiana.
371,745			371,745							Maine.
	637,894		637,894			326,461			326,461	Maryland.
1,467,761			1,467,761	$332,930		16 280,711			280,711	Massachusetts.
5,959,812			15,959,812		346,751				346,751	Michigan.
					89,052				89,052	Minnesota.
1,469,542			1,469,542							Mississippi.
										Missouri.
1,151,818	28,514		1,180,332							Montana.
1,342,447			1,342,447							Nebraska.
										Nevada.
		17 $115,022	115,022							New Hampshire.
6,894,896		1,154,266	8,049,162							New Jersey.
146,412			146,412		19 390,432				390,432	New Mexico
9,168,706			9,168,706		21 19,416,297				19,416,297	New York 20
1,781,725			1,781,725		272,924				272,924	North Carolina.
16,342			16,342					23 905,000	905,000	North Dakota.
5,178,280	(25)		15,178,280					26 239,630	239,630	Ohio.
1,990,916			1,990,916							Oklahoma.
*356,686			356,686	6,323						Oregon.
	538,919		538,919	43,316				28 35,538	35,538	Pennsylvania.
						370,389			370,389	Rhode Island.
										South Carolina.
1,030,101			1,030,101	8,533						South Dakota.
						138,376		29 1,487	139,863	Tennessee.
9,809,143			9,809,143							Texas.
										Utah.
634,335			634,335							Vermont.
								29 628	628	Virginia.
11,924			11,924							Washington.
22 641,663			641,663		30 2,392				2,392	West Virginia.
2,277,770	328,915		2,606,685	90,386	31 1,438,748				1,438,748	Wisconsin.
										Wyoming.
					32 747,561				747,561	District of Columbia.
3,035,093	1,852,451	1,269,288	86,156,832	481,488	26,759,863	1,369,738	4,405,359	1,374,711	33,909,671	Total.

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[6] Pro-rata share (approximate) of debt service on nonhighway portion of Emergency Public Works loan.

[7] Pro-rata share service of highway relief bonds, a State obligation incurred for improvement of local roads.

[8] Includes $4,594,247, pro-rata share of temporary loan to general fund for relief.

[9] To State general fund, $146,412; to county general funds, $244,020.

[0] Appropriations out of general fund for highway purposes have been credited against payments of motor-fuel tax and motor-vehicle fees to the State general fund and tted in proportion to net receipts not otherwise dedicated.

[1] To State general fund after crediting appropriations for highway purposes, $15,213,905; New York City general fund, $4,202,392.

[2] For county roads under State control.

[3] To real estate bond and interest fund, $900,000; Bureau of Criminal Identification, $5,000.

[4] General law provides that this allotment shall be used for highway purposes. It is provided, however, that during 1933, 1934, and 1935 amounts shall be paid to counties townships for other than highway purposes, equal to amounts which would have been produced by the 1930 levies on personal property for other than highway purs. Amounts so diverted not reported.

[5] Allotments to municipalities not reported separately for 1935.

[6] For hospitalization of indigent persons injured in motor-vehicle accidents.

[7] In computing adjustment, amounts loaned to general fund for relief purposes in 1934 and 1935 (pro-rata share, $3,717,186) have been included in the undistributed nces.

[8] For aircraft landing fields, $24,021; cooperative work other departments, $11,517.

[9] For aviation purposes.

[0] To cities.

[1] To towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles.

[2] To District of Columbia general fund.

DISPOSITION OF STATE MOTOR-

[Compiled from report

State	Net total receipts of calendar year	Adjustments due to undistributed balances, etc.	Net total funds distributed [2]	Expenses of collection and administration	For State highway purposes						
					Construction, maintenance, and administration [3]	State highway police	Service of State highway obligations				Total for State highway purposes
							State highway bonds	State assumed local obligations [4]	Notes and other short-term loans	Total	
Alabama	$109,592	[illegible]	[illegible]	$23,142	$54,749						$54,749
Arizona	122,394	[illegible]	[illegible]	10,653	103,930	$4,350					108,280
Arkansas	2,038		2,038		392		$769	$857	$20	$1,646	2,038
California	2,014,661	661,925	2,676,586	380,038	276,818		460,000			460,000	736,818
Colorado	294,473	−33,942	260,531	40,432	141,314						141,314
Connecticut	167,974	−16,059	151,915		48,540						48,540
Delaware											
Florida	221,216		221,216	47,227							
Georgia	298,705	−37,694	261,011	133,475	93,996						93,996
Idaho	77,231	−28,845	48,386	20,480		27,906					27,906
Illinois											
Indiana	513,783	−267,921	245,862	69,774	176,088						176,088
Iowa	431,389	−9,419	421,970	112,936							
Kansas	867,992	1,730	869,722	227,583	346,647	88,863		44,919		44,919	480,429
Kentucky	269,984	−80,050	189,934	74,985	114,664	285					114,949
Louisiana	1,142		1,142	1,142							
Maine	20,288		20,288	20,288							
Maryland											
Massachusetts	64,815		64,815	37,127							
Michigan	387,171	−298,939	88,232	87,152							
Minnesota	18,798	230	19,028	19,028							
Mississippi	100,250	−4,946	95,304	1,300							
Missouri	447,609	40,082	487,691	64,893	217,353	5,530	164,710			164,710	387,593
Montana	22,164	−3,695	18,469	18,469							
Nebraska											
Nevada	192,310		192,310	8,553	180,532	3,225					183,757
New Hampshire	2,821		2,821	2,821							
New Jersey	84,253	[15] −28,292	55,961		18,564						18,564
New Mexico	87,001	−3,397	83,604	11,400	59,470	12,734					72,204
New York											
North Carolina	132,687		132,687		41,595	1,297	47,673	2,882		50,555	93,447
North Dakota	52,373	−28,936	23,437	23,437							
Ohio	727,874		727,874	155,240	439,881	9,958					449,839
Oklahoma	796,776	−19,349	777,427	37,126	740,301						740,301
Oregon	752,177	32,485	784,662	100,380	316,787	22,902	243,522			243,522	583,211
Pennsylvania	[illegible]	[illegible]	[illegible]		5,119	178	746			746	6,043
Rhode Island	14,976		14,976	14,976							
South Carolina	87,882	−3,499	84,383	16,347	60,761						60,761
South Dakota	312,435	66,413	378,848	28,200	339,701						339,701
Tennessee	265,537	20,608	286,145	62,341	135,269		3,268		1,745	5,013	140,282
Texas	64,586	−700	63,886	54,404	9,482						9,482
Utah	267,412	1,408	268,820	31,439	228,530	8,851					237,381
Vermont											
Virginia	138,460		138,460	19,914	92,049						92,049
Washington	186,126		186,126	186,126							
West Virginia	59,632		59,632		15,729		41,536			41,536	57,265
Wisconsin	1,429,481	−15,446	1,414,035	404,364							
Wyoming	138,268		138,268	23,271	112,356	2,641					114,997
District of Columbia	166,982		166,982								
Total	12,421,383	−74,289	12,347,094	2,570,463	4,370,617	188,720	962,224	48,658	1,765	1,012,647	5,571,984

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[1] Amounts distributed during the calendar year differ in many cases from actual collections because of undistributed balances and lag between accounts of collecting and expending agencies.

[2] In many States the proceeds of motor-fuel taxes, motor-vehicle fees, and motor-carrier taxes are placed in a common fund from which the distribution is made. In these cases the amounts distributed have been prorated in proportion to the receipts, not otherwise dedicated, from these 3 sources of revenue. See preceding tables.

[3] Includes funds allotted for expenditure on urban extensions of State-highway system, where reported separately from other funds distributed for local roads and streets.

[4] County or local obligations assumed by State as reimbursement for local roads added to State system.

[5] In States indicated by star (*) law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amounts so used not reported separately.

[6] To State general funds unless otherwise noted. Allocations to county or municipal general funds may have been used in part for highways, but such amounts not reported.

[7] For engineering expenses in connection with irrigation.

ARRIER TAX RECEIPTS, 1935

ate authorities]

For local roads and streets					For nonhighway purposes					
or work n county nd local roads	For work on city streets	Service of local highway obligations	Total	For other highway purposes (park and forest roads, etc.)	To general funds	For relief of unemployment or destitution	For education	For other purposes	Total	State
$17,366			$17,366							Alabama.
								[7] $215	$215	Arizona.
										Arkansas.
277,220			277,220		$1,268,170			14,340	1,282,510	California.
78,785			78,785							Colorado.
					[10] 103,375				103,375	Connecticut.
										Delaware.
		$161,535	161,535		[10] 8,256		$4,198		12,454	Florida.
306			306		10,792			[12] 22,442	33,234	Georgia.
										Idaho.
										Illinois.
										Indiana.
*309,034			309,034							Iowa.
161,710			161,710							Kansas.
										Kentucky.
										Louisiana.
										Maine.
										Maryland.
					27,688				27,688	Massachusetts.
					1,080				1,080	Michigan.
										Minnesota.
*93,229			93,229		775				775	Mississippi.
35,205			35,205							Missouri.
										Montana.
										Nebraska.
										Nevada.
										New Hampshire.
29,876		7,521	37,397							New Jersey.
										New Mexico.
										New York.
[16] 34,028			34,028		5,212				5,212	North Carolina.
										North Dakota.
122,795			122,795							Ohio.
										Oklahoma.
*99,311			99,311	1,760						Oregon.
	130		130		1,032				1,032	Pennsylvania.
										Rhode Island.
					7,275				7,275	South Carolina.
				10,947						South Dakota.
					76,646	6,803		[19] 73	83,522	Tennessee.
										Texas.
										Utah.
										Vermont.
					26,497				26,497	Virginia.
										Washington.
[16] 2,367			2,367							West Virginia.
					1,009,671				1,009,671	Wisconsin.
										Wyoming.
					[20] 166,982				166,982	District of Columbia.
1,261,232	130	169,056	1,430,418	12,707	2,713,451	6,803	4,198	37,070	2,761,522	Total.

For service of county and city bonds.

Funds allotted to counties for use on both State and local roads.

[0] To cities and towns.

[1] No special taxes on motor carriers reported.

[2] For Confederate pensions and past-due teachers' salaries, $22,405; for prison camps, $37.

[3] Receipts from weight tax on motor carriers, $5,154, included in motor-vehicle receipts, preceding table.

[4] Ton-mile and passenger-mile taxes paid by motor carriers in lieu of registration fees included in motor-vehicle receipts, preceding table.

[5] Adjustment includes $29,937, pro-rata share of temporary loan to general fund for relief purposes.

[6] For county roads under State control.

[7] Pro-rata share of temporary loan to general fund for relief purposes.

[8] To counties and cities.

[9] Aviation projects.

[0] To district of Columbia general fund.

DISPOSITION OF RECEIPTS FROM STAT

[Compiled from repo

State	Net total receipts of calendar year [1]	Adjustments due to undistributed balances, etc.[2]	Net total funds distributed	Expenses of collection and administration [3]	For State highway purposes						
					Construction, maintenance, and administration [4]	State highway police	Service of State highway obligations				Total fo State highway purpose
							State highway bonds	State-assumed local obligations [5]	Notes and other short-term loans	Total	
Alabama	$13, 996, 855	−$18, 499	$13, 978, 356	$445, 179	$5, 853, 965	$172, 964	$1, 728, 513			$1, 728, 513	$7, 755, 44
Arizona	4, 249, 138	−18, 512	4, 230, 626	200, 065	2, 740, 164	114, 688					2, 854, 85
Arkansas	10, 793, 136	−15, 798	10, 777, 338	448, 059	1, 856, 242	86, 280	3, 643, 547	$4, 055, 430	$93, 311	7, 792, 288	9, 734, 81
California	52, 561, 118	−2, 317, 466	50, 243, 652	2, 541, 614	28, 001, 282	2, 068, 763	460, 000			460, 000	30, 530, 04
Colorado	8, 510, 936	−34, 381	8, 476, 555	486, 253	4, 456, 691	73, 128					4, 529, 81
Connecticut	11, 948, 042	−175, 283	11, 772, 759	894, 699	8, 275, 147	325, 000					8, 600, 14
Delaware	2, 553, 898	[14] 561, 169	3, 115, 067	52, 730	1, 778, 079	163, 759	89, 400	469, 930		559, 330	2, 501, 16
Florida	23, 072, 962	−10, 813	23, 062, 149	617, 069	7, 581, 351	58, 957		2, 552, 247		2, 552, 247	10, 192, 55
Georgia	17, 318, 706	−37, 694	17, 281, 012	816, 257	8, 345, 288						8, 345, 28
Idaho	5, 081, 613	−118, 426	4, 963, 187	88, 457	3, 069, 880	80, 971	207, 125			207, 125	3, 357, 97
Illinois	50, 823, 119	29, 032	50, 852, 151	1, 566, 129	17, 075, 250	893, 175	9, 081, 120	376, 789		9, 457, 909	27, 426, 33
Indiana	27, 930, 395	−321, 814	27, 608, 581	1, 057, 934	12, 749, 268	385, 227					13, 134, 49
Iowa	22, 294, 583	−317, 823	21, 976, 760	957, 916	7, 503, 053			8, 114, 757		8, 114, 757	15, 617, 81
Kansas	13, 324, 758	18, 992	13, 343, 750	865, 555	7, 697, 555	180, 640		1, 000, 000		1, 000, 000	8, 878, 19
Kentucky	13, 597, 315	−62, 475	13, 534, 840	541, 190	12, 437, 905	39, 738					12, 477, 64
Louisiana	12, 981, 491	567, 004	13, 548, 495	208, 799	2, 762, 785	342, 477	8, 365, 250			8, 365, 250	11, 470, 51
Maine	7, 829, 193	−2, 424	7, 826, 769	152, 552	4, 398, 749	250, 000	2, 110, 307			2, 110, 307	6, 759, 05
Maryland	12, 731, 465	−259, 198	12, 472, 267	336, 460	4, 519, 627	260, 699	2, 521, 146			2, 521, 146	7, 301, 47
Massachusetts	23, 704, 302	2, 824	23, 707, 126	1, 575, 587	6, 092, 412	325, 000	715 305		25, 000	740, 305	7, 157, 71
Michigan	40, 778, 840	−189, 127	40, 589, 713	1, 385, 930	12, 465, 565	250, 000	4, 082, 060			4, 082, 060	16, 797, 62
Minnesota	18, 596, 459	214, 920	18, 811, 379	964, 633	9, 736, 775	171, 409	2, 122, 000	1, 962, 820		4, 084, 820	13, 993, 00
Mississippi	9, 353, 476	−7, 729	9, 345, 747	187, 467	4, 449, 754	27, 506					4, 477, 26
Missouri	18, 604, 696	104, 781	18, 709, 477	705, 464	10, 076, 478	256, 391	7, 635, 939			7, 635, 939	17, 968, 80
Montana	5, 248, 274	37, 340	5, 285, 614	128, 967	3, 100, 035	72, 540	804, 640			804, 640	3, 977, 21
Nebraska	11, 808, 139	1, 126	11, 809, 265	172, 935	5, 945, 800	12, 500					5, 958, 30
Nevada	1, 417, 861	−17, 496	1, 400, 365	32, 666	1, 263, 052	22, 813	67, 562	14, 272		81, 834	1, 367, 69
New Hampshire	4, 562, 489	210	4, 562, 699	109, 914	3, 298, 487	136, 700	731, 848			731, 848	4, 167, 03
New Jersey	34, 913, 118	[22] −6, 032, 485	28, 880, 633	1, 194, 186	3, 343, 211		7, 597, 651			7, 597, 651	10, 940, 86
New Mexico	4, 082, 185	−17, 331	4, 064, 854	201, 289	1, 800, 291	12, 734	1, 513, 696			1, 513, 696	3, 326, 72
New York [21]	100, 267, 752	−114, 118	100, 153, 634	2, 536, 357	11, 944, 018	1, 149, 150	8, 737, 780			8, 737, 780	21, 830, 94
North Carolina	25, 916, 450	650, 433	26, 566, 883	353, 237	7, 979, 927	218, 825	9, 146, 145	553, 007		9, 699, 152	17, 927, 90
North Dakota	3, 798, 455	−187, 978	3, 610, 477	157, 016	1, 739, 384	26, 959					1, 766, 34
Ohio	61, 432, 603	−1, 226, 714	60, 205, 889	1, 660, 017	20, 909, 973	473, 346					21. 383, 31
Oklahoma	16, 535, 293	−387, 209	16, 148, 084	817, 841	6, 936, 338						6, 936, 33
Oregon	11, 443, 279	−59, 695	11, 383, 584	441, 799	5, 103, 775	283, 256	3, 923, 391			3, 923, 391	9, 310, 42
Pennsylvania	69, 418, 399	[33] −1, 289, 503	68, 128, 896	1, 601, 273	43, 866, 369	1, 531, 849	6, 414, 693			6, 414, 693	51, 812, 91
Rhode Island	5, 021, 642	56, 865	5, 078, 507	291, 417	3, 813, 464		301, 876			301, 876	4, 115, 34
South Carolina	10, 644, 681	−82, 657	10, 562, 024	236, 095	4, 318, 978	149, 265	1, 339, 386	3, 024, 084	652	4, 364, 122	8, 832, 36
South Dakota	5, 998, 880	94, 483	6, 093, 363	144, 228	2, 482, 433						2, 482, 43
Tennessee	18, 663, 870	221, 397	18, 885, 267	427, 024	4, 990, 330	190, 922	120, 100	2, 133, 833	4, 132, 610	6, 386, 543	11, 567, 79
Texas	49, 416, 568	−87, 991	49, 328, 577	1, 285, 306	21, 345, 965	308, 041		8, 290, 061		8, 290, 061	29, 944, 06
Utah	4, 052, 400	−261, 315	3, 791, 085	139, 204	2, 805, 713	108, 668	737, 500			737, 500	3, 651, 88
Vermont	3, 425, 886	1, 427, 761	4, 853, 647	46, 691	2, 584, 430	73, 309	949, 131			949, 131	3, 606, 87
Virginia	18, 629, 720	−137, 428	18, 492, 292	525, 363	10, 922, 651	194, 960	649, 679			649, 679	11, 767, 29
Washington	16, 249, 758		16, 249, 758	549, 971	6, 671, 974	507, 098	[40] 97, 930			97, 930	7, 277, 00
West Virginia	10, 983, 210	−1, 741	10, 981, 469	71, 927	2, 744, 582	29, 277	7, 248, 016			7, 248, 016	10, 021, 87
Wisconsin	28, 576, 260	−1, 168, 044	27, 408, 216	1, 331. 866	10, 485, 808			3, 815, 721		3, 815, 721	14, 301, 52
Wyoming	2, 553, 073	80, 989	2, 634, 062	43, 792	1, 669, 285	45, 778	278, 000			278, 000	1, 993, 06
District of Columbia	3, 274, 417	374, 793	3, 649, 210	162, 665							
Total	950, 971, 158	−10, 535, 048	940, 436, 110	31, 761, 144	375, 989, 538	12, 104, 762	93, 420, 736	36, 362, 951	4, 251, 573	134, 035, 260	522, 129, 56

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[1] Includes receipts from (1) motor-fuel taxes, (2) motor-vehicle fees and fines, and (3) special imposts on motor vehicles operated for hire (motor-carrier taxes). preceding tables, which give distribution of these three classes of receipts separately.

[2] Amounts distributed during the calendar year differ in many cases from actual collections because of undistributed balances and lag between accounts of collecti and expending agencies. Adjustments also include deduction of receipts not classed as highway-user imposts as follows: Proceeds of tax on gasoline used in aviation Idaho, Maine, Michigan, Nebraska, Oregon, and Wyoming, and proceeds of tax on nonmotor-vehicle fuel in Ohio.

[3] Includes expenses of collection and administration of motor-fuel tax, motor-vehicle fees, and motor-carrier taxes, and miscellaneous expenses of motor-vehicle regu tion.

[4] Includes funds allotted for expenditure on urban extensions of State highway system, where reported separately from other funds distributed for local roads a streets.

[5] County or local obligations assumed by State as reimbursement for local roads added to State system.

[6] In States indicated by star (*) law provides that allotments for work on local roads or streets may also be used for service of local highway obligations, but amou so used not reported separately.

[7] In a number of States allotments for local road work may be used on city streets. This column shows allotments which were reported separately. See note 4.

[8] To State general funds unless otherwise noted. Allocations to county or municipal general funds may have been used in part for highways, but such amounts reported.

[9] To county and municipal general funds

[10] For engineering expenses in connection with irrigation.

[11] For service of county and city bonds.

[12] Funds allotted to counties for use on both State and local roads.

[13] To cities and towns.

[14] State highway sinking fund transferred to general fund as a result of refunding operation which replaced sinking-fund bonds with serial bonds.

[15] Includes $8,256 to cities and towns.

[16] To Division of Airways, $15,616; Dade Memorial Park, $818.

[17] For Confederate pensions and past-due teachers' salaries, $2,000,000; prison camps, $3,322.

[18] To ports of New Orleans and Lake Charles Harbor for harbor improvement.

[19] To Conservation Department for oyster propagation, $75,000; Chesapeake Bay ferry companies, $48,727.

[20] Debt service on nonhighway portion of emergency Public Works loan.

[21] Service of highway relief bonds, a State obligation incurred for improvement of local roads.

IMPOSTS ON HIGHWAY USERS, 1935

of State authorities]

For local roads and streets [6]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes					State
For work on county and local roads	For work on city streets [7]	Service of local highway obligations	Total		To general fund	For relief of unemployment or destitution	For Education	For other purposes	Total	
$5,124,552			$5,124,552		[9] $653,183				$653,183	Alabama.
*983,365			983,365			$186,667		[10] $5,677	192,344	Arizona.
512,731		$81,738	594,469							Arkansas.
*15,707,322	$182,161		15,889,483		1,268,170			[11] 14,340	1,282,510	California.
[12] 2,476,206			2,476,206		730,476	253,801			984,277	Colorado.
2,174,538			2,174,538		[13] 103,375				103,375	Connecticut.
					[14] 561,169				561,169	Delaware.
		5,266,030	5,266,030		[15] 2,560,504		$4,409,557	[16] 16,434	6,986,495	Florida.
2,537,319			2,537,319		963,349		2,615,477	[17] 2,003,322	5,582,148	Georgia.
*1,516,754			1,516,754							Idaho.
*7,756,878	*6,596,832		14,353,710		289,237	3,512,788	3,703,953		7,505,978	Illinois.
8,785,708	2,196,427		10,982,135		2,434,017				2,434,017	Indiana.
*5,401,034			5,401,034							Iowa.
3,600,000			3,600,000							Kansas.
516,007			516,007							Kentucky.
							934,592	[18] 934,592	1,869,184	Louisiana.
915,161			915,161							Maine.
779,019	2,950,062	642,106	4,371,187		12,960	326,461		[19] 123,727	463,148	Maryland.
3,840,500			3,840,500	$871,134	9,527,688	[20] 734,500			10,262,188	Massachusetts.
*22,053,997			22,053,997		352,161				352,161	Michigan.
*3,697,644			3,697,644		156,098				156,098	Minnesota.
*4,680,245			4,680,245		775				775	Mississippi.
35,205			35,205							Missouri.
1,151,818	28,514		1,180,332							Montana.
*4,243,632	321,180		4,564,812			1,113,218			1,113,218	Nebraska.
										Nevada.
		285,750	285,750							New Hampshire.
9,690,450		1,354,550	11,045,000			3,964,062	1,332,500	[23] 404,023	5,700,585	New Jersey.
146,412			146,412		[24] 390,432				390,432	New Mexico.
*17,259,477			17,259,477		[26] 58,526,852				58,526,852	New York [25]
[27] 6,528,280			6,528,280		1,757,462				1,757,462	North Carolina.
781,342			781,342		776			[28] 905,000	905,776	North Dakota.
[29] *22,506,475	[30] 4,929,445		27,435,920				9,487,003	[31] 239,630	9,726,633	Ohio.
*4,899,899			4,899,899		3,228			[32] 3,490,778	3,494,006	Oklahoma.
*1,600,000			1,600,000	28,363						Oregon.
*8,345,374	1,118,410		9,463,784	89,883	1,032	5,086,269		[34] 73,744	5,161,045	Pennsylvania.
						671,750			671,750	Rhode Island.
*1,352,684			1,352,684		[35] 140,880				140,880	South Carolina.
1,030,101			1,030,101	80,000	114,425			[36] 2,242,176	2,356,601	South Dakota.
4,232,978			4,232,978		76,646	250,000		[37] 2,330,824	2,657,470	Tennessee.
*9,809,143			9,809,143				8,290,061		8,290,061	Texas.
										Utah.
1,200,086			1,200,086							Vermont.
[38] 6,170,790			6,170,790		26,467			[39] 2,382	28,849	Virginia.
*6,523,604	994,320	[40] 79,574	7,597,498			[40] 825,287			825,287	Washington.
[27] 885,275			885,275		[41] 2,392				2,392	West Virginia.
5,667,153	818,351		6,485,504	200,000	[42] 5,089,317				5,089,317	Wisconsin.
597,207			597,207							Wyoming.
	2,572,002		2,572,002		[43] 914,543				914,543	District of Columbia.
207,716,365	22,707,704	7,709,748	238,133,817	1,269,380	86,657,644	16,924,803	30,773,143	12,786,619	147,142,209	Total.

[22] Includes $5,391,424 temporary loan to general fund for relief.

[23] For service of institutional construction bonds, $434,468; Department of Commerce and Navigation, $90,000, less credit for excess allocations in 1934, (−) $120,445.

[24] To State general fund, $146,412; to county general funds, $244,020.

[25] Appropriations out of general fund for highway purposes have been credited against payments of motor-fuel tax and motor-vehicle fees to the State general fund and prorated in proportion to net receipts not otherwise dedicated.

[26] To State general fund after crediting appropriations for highway purposes, $52,828,892; New York City general fund, $5,697,960.

[27] For county roads under State control.

[28] To real estate bond and interest fund, $900,000; Bureau of Criminal Identification, $5,000.

[29] Law provided for partial diversion of county and township allotments to general funds. Amounts so used not reported separately.

[30] Allotment from motor-fuel tax only. Municipal allotments from motor-vehicle fees not reported separately in 1935.

[31] For hospitalization of indigent persons injured in motor-vehicle accidents.

[32] For service of general State debt.

[33] In computing adjustment, amounts loaned to general fund for relief purposes in 1934 and 1935, $7,340,000, have been included in the undistributed balances.

[34] For aircraft landing fields, $49,845; cooperative work, other departments, $23,899.

[35] To State general fund, $133,605; to counties and cities, $7,275.

[36] For payments on real-estate bonds.

[37] Service of general-fund bonds, $2,116,489; Great Smoky Mountain Park bonds, $211,649; aviation projects, $2,686.

[38] For county roads under State control in all but three counties, $5,944,322; transferred to remaining three counties, $226,468.

[39] For aviation purposes.

[40] Debt service charges on $10,000,000 emergency relief bond issue prorated in proportion to allotments for State highways, local roads, and nonhighway purposes.

[41] To cities.

[42] Includes $1,509,671 to State general fund and $3,579,646 to towns, cities, and villages in lieu of personal-property tax formerly imposed on motor vehicles.

[43] To District of Columbia general fund

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

1936 -1937

AS OF NOVEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287	$ 51,600	$ 25,800	9.0	$ 710,181	$ 355,090	20.1	$ 730,700	$ 365,350	35.3	$ 4,462,047
Arizona	3,564,709	1,777,992	1,378,202	98.3	1,019,637	807,343	41.2	254,800	179,220	7.3	1,199,944
Arkansas	4,275,929							1,765,401	1,764,739	60.0	2,511,190
California	9,508,671	3,259,773	1,884,211	88.9	9,341,966	5,348,228	246.7	2,778,299	1,599,878	60.3	676,354
Colorado	4,575,144	2,914,634	1,543,884	109.8	3,277,034	1,804,071	118.7	1,280,437	715,991	50.7	511,198
Connecticut	1,582,913	491,273	245,937	9.5	727,093	361,344	6.9	120,800	60,240	3.8	915,393
Delaware	1,218,750	305,920	152,960	30.3	339,069	164,048	9.9	436,402	204,962	14.8	696,780
Florida	3,315,558	831,120	415,560	27.5	598,555	299,273	19.3	542,200	271,100	20.9	2,329,625
Georgia	6,336,443	936,738	436,776	72.1	2,435,848	1,217,904	128.7	921,133	450,951	39.0	4,230,811
Idaho	3,065,304	1,927,993	1,145,730	235.2	1,450,283	867,845	73.8	406,340	243,151	22.6	808,578
Illinois	10,325,922	5,190,075	2,589,322	90.2	6,858,774	3,394,913	135.9	4,018,070	1,983,610	98.8	2,358,078
Indiana	6,184,258	4,294,269	2,143,161	133.3	2,769,971	1,384,046	88.5	3,657,650	1,828,258	88.2	828,792
Iowa	6,466,628	6,757,971	3,196,508	445.5	3,342,843	1,621,270	134.7	2,090,518	1,010,224	64.0	638,626
Kansas	6,631,085	2,903,124	1,500,886	599.0	4,629,975	2,288,486	357.5	2,212,052	1,106,010	114.7	1,735,703
Kentucky	4,611,955	2,185,437	1,071,030	142.0	974,931	487,466	23.8	872,456	431,784	41.2	2,621,676
Louisiana	3,557,930	1,463,014	729,308	52.9	1,204,776	602,374	41.3	593,690	296,845	13.1	1,929,403
Maine	2,177,197	1,904,831	951,618	58.7	799,888	399,944	18.5	295,120	147,560	8.6	678,075
Maryland	2,050,870				924,493	462,212	12.9	804,838	361,896	10.9	1,226,761
Massachusetts	3,485,364	333,935	166,968	3.1	4,490,403	2,195,201	17.5	14,206	7,102		1,116,093
Michigan	7,668,768	5,517,385	2,754,470	224.5	8,371,468	4,185,734	225.2	1,204,594	611,297	35.5	117,267
Minnesota	6,849,307	7,879,557	3,702,191	522.3	2,331,861	1,162,143	118.2	1,561,964	780,982	58.6	1,203,991
Mississippi	4,387,636				294,105	147,052	16.3	1,133,470	567,035	70.9	3,673,548
Missouri	7,601,200	3,456,539	1,724,004	422.8	6,537,120	3,267,422	241.3	2,529,454	1,390,349	119.2	1,219,426
Montana	5,122,333	3,760,971	2,105,635	384.1	2,697,817	1,510,508	172.3	649,237	325,316	29.2	1,180,875
Nebraska	5,167,930	2,593,781	1,294,944	164.9	2,801,922	1,406,543	284.0	61,709	30,855	4.8	2,435,588
Nevada	3,189,479	1,448,617	1,249,457	269.5	691,420	594,683	14.3	9,600	8,300	.5	1,337,039
New Hampshire	1,218,750	758,362	372,685	22.5	286,182	142,523	4.6	10,550	5,275		698,267
New Jersey	3,352,469	1,833,713	916,837	28.1	2,680,249	1,262,830	26.1	324,309	162,155	5.4	1,010,648
New Mexico	3,990,023	2,671,651	1,623,798	208.7	1,935,274	1,196,066	171.2	908,535	552,567	33.1	617,593
New York	12,306,710	5,511,336	2,734,167	116.2	15,312,574	7,545,887	260.2	2,310,688	1,146,199	28.6	880,457
North Carolina	5,879,466	1,989,822	994,050	254.2	2,705,079	1,325,591	247.6	1,905,773	883,086	76.1	2,676,738
North Dakota	3,918,269				400,450	212,950	.4				3,705,319
Ohio	9,131,204	1,474,536	737,268	26.9	6,737,210	3,183,286	71.2	587,960	292,480	5.8	4,918,170
Oklahoma	5,884,927	2,153,021	1,122,895	76.9	1,714,378	898,650	60.3	1,113,320	529,529	43.1	3,333,853
Oregon	4,089,711	2,348,344	1,416,769	92.9	2,983,384	1,777,026	104.1	577,124	324,210	24.1	571,706
Pennsylvania	10,695,448	5,289,095	2,644,102	89.8	7,762,600	3,873,366	105.8	2,735,688	1,355,849	37.8	2,822,131
Rhode Island	1,218,750	23,810	11,905	.3	593,768	296,884	6.6	486,757	243,379	4.2	666,582
South Carolina	3,381,337	32,682	15,000	8.7	3,235,070	1,309,620	239.1	1,818,052	718,750	124.8	1,337,967
South Dakota	4,078,647	1,396,263	784,004	188.6	73,791	51,239	16.4	379,240	207,880	48.9	3,035,523
Tennessee	5,268,270	1,915,051	955,398	80.3	857,474	428,732	33.0	302,878	151,439	10.0	3,732,701
Texas	15,548,821	9,281,213	4,629,891	526.8	5,658,953	2,825,805	264.3	2,668,582	1,330,044	167.0	6,763,081
Utah	2,826,960	1,995,520	1,428,579	137.9	537,531	386,605	34.2	586,439	394,547	38.8	617,229
Vermont	1,218,750	1,323,336	659,042	62.9	763,404	354,753	20.2	129,620	64,750	4.3	140,205
Virginia	4,559,200	2,157,864	1,076,576	85.8	2,144,464	1,072,229	97.9	1,954,728	977,360	55.8	1,433,034
Washington	3,904,738	2,926,718	1,540,903	100.9	2,634,116	1,383,771	127.4	391,112	205,100	6.8	774,964
West Virginia	2,716,754	398,060	199,030	22.5	1,134,980	567,473	36.1	779,046	389,523	17.3	1,560,728
Wisconsin	6,090,504	3,675,354	1,755,618	150.3	4,058,518	1,975,646	139.8	457,915	227,825	18.3	2,131,415
Wyoming	3,121,972	2,780,220	1,696,458	347.3	1,179,293	730,843	145.0	152,790	94,100	30.8	600,571
District of Columbia											
Hawaii	1,218,750				467,855	231,167	8.2	69,938	34,754	1.6	952,829
TOTALS	243,750,000	114,123,120	59,723,537	6,821.9	135,478,030	69,368,085	4,787.2	51,596,184	27,033,806	1,855.5	87,624,572

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF NOVEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 954,131	$ 954,131	51.0	$ 3,050,432	$ 3,050,432	78.5	$ 68,086	$ 68,086	8.7	$ 78,465
Arizona	2,569,841	2,435,172	2,184,031	161.8	563,100	336,434	27.2				49,375
Arkansas	3,352,061	2,150,928	2,133,168	208.9	1,126,473	1,124,671	138.2	55,329	55,221	11.9	39,001
California	7,747,928	4,204,519	4,023,801	197.3	2,998,628	2,975,468	56.7	69,672	69,672	1.2	78,987
Colorado	3,395,263	1,892,021	1,835,276	93.1	239,486	239,469	11.0				1,270,518
Connecticut	1,418,709	166,679	159,804	.2	619,224	581,031	8.6	294,306	294,306	8.9	383,567
Delaware	900,310	[illegible]	[illegible]	33.3	575,071	467,425	29.5	106,430	106,420	4.0	145,946
Florida	2,547,144	[illegible]	[illegible]	34.4	1,712,444	1,712,444	64.3	70,781	70,781	.4	44,294
Georgia	[illegible]	439,320	438,662	29.0	660,418	660,318	42.3	469,634	469,634	33.9	3,419,853
Idaho	2,226,747	1,734,459	1,692,671	[illegible]	[illegible]	490,540	37.7	21,660	21,660	2.4	17,876
Illinois	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	96.7	219,610	219,610	16.6	13,905
Indiana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	168.8	37,924	37,924	6.3	61,343
Iowa	[illegible]	[illegible]	[illegible]	[illegible]	3,076,433	2,922,585	205.8	72,044	18,200	7.0	1,375
Kansas	4,944,975	[illegible]	[illegible]	211.3	3,024,394	[illegible]	163.8				74
Kentucky	3,726,271	1,732,305	1,724,277	[illegible]	1,424,506	1,424,506	105.6	355,705	355,636	8.1	221,691
Louisiana	2,890,429	939,645	802,230	53.5	1,851,075	1,654,642	104.8	335,053	275,018	16.4	158,539
Maine	1,676,799	1,171,746	1,170,514	49.9	405,523	405,523	20.5	84,600	84,600	2.5	16,161
Maryland	1,750,738	186,296	186,296	10.7	663,463	623,593	13.0	626,424	502,954	17.9	437,896
Massachusetts	3,262,885	117,754	117,754	1.1	2,034,905	2,034,905	16.6	856,377	503,016	.7	607,210
Michigan	6,301,414	5,156,800	5,096,270	244.3	1,046,421	1,046,421	43.6	203,200	158,200	4.8	523
Minnesota	5,277,145	4,971,518	4,218,675	806.1	1,279,576	878,731	95.8	163,066	130,198	2.5	49,542
Mississippi	3,457,552	1,530,341	1,526,274	116.7	1,555,771	1,554,402	88.3	315,059	315,059	27.1	61,817
Missouri	6,012,652	3,251,055	3,219,982	685.8	2,405,820	2,289,863	90.2	602,777	435,632	1.7	67,175
Montana	3,676,416	3,261,295	3,260,629	134.7	371,674	363,704	10.6				52,083
Nebraska	3,370,739	1,966,679	1,922,319	202.5	1,579,504	1,578,000	155.2	118,088	118,088	12.2	252,333
Nevada	2,243,074	1,656,964	1,635,081	75.5	336,756	336,756	16.0	2,738	2,738	.3	267,498
New Hampshire	945,225	491,748	476,066	24.3	260,796	250,723	8.3	89,423	87,975	1.8	130,461
New Jersey	3,129,805	571,768	571,769	13.2	2,287,721	2,271,566	15.9	207,045	198,076	4.7	88,394
New Mexico	2,871,397	2,037,358	2,036,654	156.7	605,318	605,318	36.1	156,277	156,277	5.8	73,148
New York	11,046,377	6,148,781	5,852,919	116.5	4,976,530	4,848,730	51.4	328,700	328,700	2.5	6,028
North Carolina	4,720,173	1,282,143	1,282,143	85.0	3,069,133	3,036,544	182.7	300,671	234,131	19.4	167,355
North Dakota	2,867,245	1,202,148	1,200,622	182.7	1,298,432	1,294,997	122.9	154,511	154,511	20.2	217,115
Ohio	7,670,815	2,233,273	2,210,463	78.4	4,279,746	4,156,035	147.7	1,085,310	1,068,105	65.5	236,212
Oklahoma	4,580,670	1,597,823	1,587,446	157.9	1,904,258	1,902,575	198.8	769,949	757,963	46.3	332,687
Oregon	3,038,642	1,960,160	1,941,326	148.5	1,253,621	892,185	8.8	69,992	69,992	9.5	135,139
Pennsylvania	9,347,797	1,236,303	1,234,044	67.4	1,953,278	1,949,240	57.9	2,117,071	2,116,182	69.2	4,047,731
Rhode Island	989,208	730,530	720,034	15.4	259,501	259,501	3.4	9,673	9,673		
South Carolina	2,702,012	739,721	703,539	79.3	1,480,601	1,421,787	131.2	271,363	254,009	19.1	322,678
South Dakota	2,976,454	1,527,862	1,527,862	342.1	897,926	897,926	100.4	307,147	307,147	39.1	143,519
Tennessee	4,192,460	1,558,721	1,554,796	71.8	1,496,888	1,496,388	51.9	506,607	506,607	18.4	634,169
Texas	11,989,350	9,515,614	8,624,872	868.5	3,534,481	3,230,556	243.4	188,047	89,975	10.0	43,948
Utah	2,067,154	1,353,522	1,222,977	152.4	672,601	641,237	35.8	112,860	112,860	5.0	90,080
Vermont	924,306	784,678	687,532	18.8	237,731	193,455	3.0	33,020	19,910	.4	23,410
Virginia	3,652,667	2,608,384	[illegible]	829.8	767,689	767,509	180.9	189,806	189,806	31.8	169,230
Washington	3,026,161	2,449,980	[illegible]	155.2	838,107	692,716	8.3	92,098	92,098	1.2	21,269
West Virginia	2,231,412	194,382	194,382	11.8	1,801,289	1,747,745	67.9	128,465	127,732	10.3	111,553
Wisconsin	4,823,884	4,600,425	4,135,575	309.2	907,340	678,123	31.5	2,030	2,030	2.9	8,156
Wyoming	2,219,155	1,340,460	1,340,443	109.0	859,398	840,528	31.1				38,184
District of Columbia	949,496	909,101	909,101	3.5	46,898	21,660	.4				18,735
Hawaii	926,033	243,307	229,809	4.0	401,855	395,297	4.9	54,422	53,884	1.5	248,044
TOTALS	195,000,000	100,374,686	90,713,655	8,543.1	75,037,283	71,931,196	3,613.9	12,323,050	11,250,356	580.1	15,104,793

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF NOVEMBER 30, 1936

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
				NUMBER					NUMBER					NUMBER			
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 606,753	$ 606,753	11		4	$ 2,961,384	$ 2,961,384	36			$ 313,047	$ 313,047	3		8	$ 153,434
Arizona	1,256,099	618,960	614,726	7			566,261	554,816	6								86,557
Arkansas	3,574,060	1,135,951	1,131,534	29	4		1,726,035	1,723,087	22	1		662,597	661,542	8	1	29	57,797
California	7,426,362	2,946,341	2,840,344	19	6		4,467,330	4,329,593	25	2							316,426
Colorado	2,531,567	1,075,063	1,055,063	20			868,611	868,583	7	1							707,921
Connecticut	1,712,684						563,087	491,009	3	1	1	494,014	494,014	1	2		727,661
Delaware	413,239						143,456	120,000	1								298,239
Florida	2,327,883	660,331	658,600	5	4		1,431,369	1,430,789	17	2		456,292	456,292	7			282,202
Georgia	4,795,949	12,090	12,090	1			354,170	354,170	6	2		510,359	510,359	17			4,019,330
Idaho	1,574,479	824,073	821,481	13	1		413,637	413,637	6			64,486	64,486	1		18	374,874
Illinois	10,307,184	2,423,431	2,422,394	31			5,523,177	5,523,177	32	5		2,139,800	2,139,800	11	2		216,313
Indiana	5,111,096	497,831	497,831	8			4,373,258	4,250,139	35	11		399,720	363,120			162	6
Iowa	5,600,579	1,507,566	1,460,776	40	4		3,568,132	3,531,469	59	5		691,074	574,020	11		8	34,414
Kansas	5,246,258	682,865	682,865	9		1	4,572,084	4,516,657	47	1		46,736	46,736	2		3	
Kentucky	3,572,387	265,336	265,336	7	1		2,463,277	2,173,545	13	2		134,304	134,304	1	3		1,099,203
Louisiana	3,213,467						1,447,148	1,447,148	14	1		966,512	922,046	8	3		844,272
Maine	1,425,861	493,350	493,016	12			584,695	584,103	8			81,675	81,675	1		2	268,066
Maryland	2,961,751						615,019	615,019	4	3		921,502	899,033	3	2	19	547,699
Massachusetts	4,210,833	197,672	197,672	2	1		2,634,481	2,634,481	19	2		382,770	382,770	2			995,910
Michigan	6,765,197	2,231,975	2,231,975	26	4		4,554,297	4,509,797	19	4							23,425
Minnesota	5,395,441	2,334,936	2,206,491	51	8	38	3,061,801	2,893,610	35	4	3	56,140	56,140		1	1	239,200
Mississippi	3,241,475	207,504	207,504	8	3		2,331,184	2,331,184	42		1	56,000	56,000	4		3	646,786
Missouri	6,142,153	308,981	308,981	6			5,695,929	5,499,685	46			367,252	253,300	1		2	80,187
Montana	2,722,327	2,250,014	2,250,014	32	6		403,583	403,583	5								68,730
Nebraska	3,556,441	1,441,856	1,440,533	55	1		1,588,885	1,588,885	23	1	5	434,876	434,876	5	1	20	92,147
Nevada	837,260	370,830	370,830	8			531,025	512,800	2	1		3,630	3,630			5	
New Hampshire	822,484	151,745	151,745	1	2		350,493	350,493	6	2	1						320,246
New Jersey	3,933,826	59,838	59,838		1		2,478,788	2,467,743	17	1		163,319	163,319	1	2		1,292,927
New Mexico	1,725,286	665,807	665,807	12			865,128	865,127	5	1		194,352	194,352	2			
New York	13,577,189	1,801,823	1,737,023	9	7		9,957,801	9,701,755	31	31		256,120	256,120		4		1,822,291
North Carolina	4,823,958	579,548	579,548	9	6		2,272,573	2,257,073	27	9		1,108,520	1,108,520	10	2	61	878,817
North Dakota	3,207,473	399,891	399,891	12			1,765,711	1,764,711	29	3		456,190	456,190	10	1		586,681
Ohio	8,439,897						4,393,291	4,179,991	27	3		3,202,400	3,039,096	17	4		1,220,810
Oklahoma	5,004,711	1,208,387	1,208,387	26	1		1,918,749	1,918,749	22	3		385,124	385,124	6	2		1,492,450
Oregon	2,334,204	562,923	562,923	7	3		1,804,273	1,722,133	9	3	1	38,350	38,350	1		1	10,798
Pennsylvania	11,433,613	390,192	338,959	17			6,341,869	5,792,969	42	14	9	2,221,625	2,218,877	11	3		3,132,808
Rhode Island	699,691	398,464	398,464	2	1		277,805	276,739	2	1							24,488
South Carolina	3,059,956	441,975	434,323	11	2	3	1,416,102	1,405,024	26	6		218,406	218,356		1	51	1,002,253
South Dakota	3,249,086	568,566	568,566	17	1	5	1,508,246	1,508,246	37	2	9	325,656	325,656	5	1	17	846,619
Tennessee	3,903,979	260,278	260,278	6		6	1,548,820	1,548,820	21	2	3	563,646	563,646	9	1	13	1,531,235
Texas	10,855,982	2,739,082	2,739,082	48	8		6,915,308	6,908,931	78	5		765,488	765,487	3	1	170	442,483
Utah	1,230,763	87,218	85,828	1	1		1,015,391	998,743	14			93,695	93,695	2			52,496
Vermont	729,857	461,762	457,829	7	5		204,074	187,995	1	1	9	64,345	34,745	2		5	49,288
Virginia	3,774,287	853,786	782,923	23	3		1,343,569	1,304,569	15	7		551,960	551,959	10	4	11	1,134,837
Washington	3,095,041	868,175	863,344	15	3	5	1,964,763	1,964,338	8	8		4,290	4,290			2	263,070
West Virginia	2,677,937						1,225,701	1,225,676	11	2		493,227	493,227	10	1	4	959,033
Wisconsin	5,022,683	1,661,704	1,661,704	21	2		2,785,641	2,720,560	16	4		536,470	475,000		1		165,418
Wyoming	1,360,841	251,237	251,131	4			863,106	828,101	8								281,609
Dist. of Columbia	410,804						425,564	396,804	3								14,000
Hawaii	453,703						522,380	453,703	5								
TOTALS	196,000,000	37,507,610	37,045,002	648	89	62	111,613,591	109,016,343	992	157	42	20,825,969	20,233,199	185	43	615	29,705,456

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Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

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CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF NOVEMBER 30, 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 1934 Funds	Act of June 18, 1934 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$15,386,528	$ 8,304,382	$ 3,584,390	760.1	$ 394,771	$ 52,665	$ 339,310	15.8		$ 309,252	2.5	$ 13,085	$ 26,890
Arizona	5,211,960	2,641,935	8,981,796	5,204,512	2,605,036	542.9	12,500		12,500					7,448	24,399
Arkansas	6,748,335	3,428,049	10,920,752	6,633,093	3,320,347	619.3	143,231	70,019	72,991	4.0	$ 31,389	7,200	10.9	13,834	27,511
California	15,607,354	7,932,206	30,579,892	15,582,063	7,769,804	758.7	115,026		115,016			820		25,291	46,567
Colorado	6,874,530	3,485,906	11,357,228	6,870,681	3,441,857	639.0	6,519		6,519					3,849	37,530
Connecticut	2,865,740	1,454,868	4,514,547	2,758,269	1,312,944	74.0	59,618	59,618		.1				47,854	141,924
Delaware	1,819,088	923,395	2,680,794	1,818,804	815,188	128.3	109,467		105,524	1.6				284	2,682
Florida	5,231,834	2,661,343	8,897,743	5,175,534	2,344,564	305.5	254,979		230,665	4.0	56,300	67,339	.5		18,775
Georgia	10,091,085	5,108,491	13,210,656	9,317,893	3,163,476	743.7	1,076,421	408,589	667,832	81.9	84,072	165,358	3.5	280,531	1,111,825
Idaho	4,486,249	2,277,486	7,024,481	4,416,568	2,185,517	500.5	54,134		52,034	.1	60,771	1,886	.9	8,910	38,049
Illinois	11,570,775	8,921,401	25,748,361	10,893,752	7,817,215	708.4	1,784,642	594,214	1,068,172	15.8	37,300	7,100	12.8	45,509	28,911
Indiana	10,037,843	5,088,963	15,360,433	9,896,355	4,733,207	474.1	373,636	129,083	244,553	11.0		58,728		12,405	52,475
Iowa	10,055,660	5,118,361	15,454,949	10,054,900	4,797,361	1,222.2	340,073		321,000	5.1	499			261	
Kansas	10,089,604	5,117,575	15,427,520	10,089,600	4,996,568	1,132.3	126,943		61,887	13.1				4	59,120
Kentucky	7,517,359	3,818,311	11,961,870	7,448,139	3,571,867	807.7	275,154	59,003	214,500	8.0	8,569	23,250		1,649	8,694
Louisiana	5,828,591	2,963,932	8,482,708	5,731,008	2,592,759	252.5	318,465	56,549	198,434	13.4		128,372	5.2	41,034	44,367
Maine	3,369,917	1,711,586	5,244,109	3,346,879	1,669,075	193.5	22,234	15,000	7,234			26,540	1.4	8,038	8,737
Maryland	3,564,527	1,810,063	5,536,045	3,477,038	1,010,456	48.5	162,147		161,772	5.3		285,453	7.3	87,489	352,376
Massachusetts	6,597,100	3,350,474	9,869,513	6,552,734	2,659,290	115.2	420,416		420,416	.3		91,944	.1	44,367	178,824
Michigan	12,636,227	6,452,568	20,602,589	12,596,114	6,264,495	766.9	158,750	40,113	47,600	1.2		136,788	.4		3,685
Minnesota	10,656,569	5,425,551	16,091,251	10,514,422	4,745,392	1,632.0	473,903	58,110	376,135	17.2		34,800	.6	84,036	269,224
Mississippi	6,978,675	3,540,227	12,693,004	6,735,410	2,992,548	721.4	653,726	188,861	464,865	22.7	3,960	41,503	1.9	50,445	41,211
Missouri	12,180,306	6,173,740	17,411,196	11,637,146	4,720,320	1,436.7	2,178,630	471,210	1,334,260	15.1		62,100		71,949	57,061
Montana	7,439,748	3,769,734	11,799,494	7,425,476	3,701,189	1,058.4	56,546		56,546					14,272	11,999
Nebraska	7,828,961	3,964,364	12,828,547	7,813,593	3,604,469	1,018.3	282,047		274,622	27.8		63,537	5.9	15,368	21,736
Nevada	4,545,917	2,302,356	7,066,551	4,545,917	2,268,591	758.8	25,004		25,004			1,650			7,111
New Hampshire	1,909,839	969,462	3,003,046	1,904,951	950,495	78.3	4,174		4,174					4,888	14,793
New Jersey	6,346,039	3,220,879	8,255,287	6,046,046	1,607,061	82.0	1,964,004	120,518	1,409,346	14.1	82,145	99,275	.6	97,330	105,197
New Mexico	5,792,935	2,941,700	8,788,982	5,734,176	2,827,536	743.9	107,130		107,130	5.9		2,695		58,759	4,338
New York	22,330,101	11,327,921	38,763,582	21,778,431	10,094,963	815.4	1,751,430	399,810	982,899	8.3	133,947	162,275	1.3	17,913	87,784
North Carolina	9,522,293	4,840,941	14,341,750	9,159,957	4,505,525	1,342.1	365,770	291,910	73,860	15.3	51,017	200,873	8.1	19,408	60,683
North Dakota	5,804,448	2,938,967	8,367,434	5,609,002	2,025,164	2,094.0	486,658	114,325	350,874	49.2	15,703	101,140	17.0	65,418	461,789
Ohio	15,484,592	7,865,012	24,406,155	15,352,665	7,212,293	784.7	620,238	73,790	517,531	11.4	34,023	87,639	4.3	24,114	47,549
Oklahoma	9,216,798	4,685,180	14,535,440	9,146,565	4,303,265	804.9	182,756	67,007	115,749	1.5		174,301	.2	3,226	91,865
Oregon	6,106,896	3,097,814	9,882,293	6,039,064	2,923,060	467.6	95,469	11,308	84,161	1.2		27,241		56,525	63,352
Pennsylvania	18,891,004	9,590,788	28,714,652	18,496,822	8,746,721	1,050.6	516,605	96,463	377,896	6.0	153,388	158,223	4.3	144,331	307,948
Rhode Island	1,998,708	1,014,572	3,144,150	1,998,708	1,012,094	89.1									2,478
South Carolina	5,459,165	2,770,954	7,914,944	5,239,171	2,379,367	614.7	336,927	158,946	166,496	12.3	46,320	119,798	2.1	14,728	105,293
South Dakota	6,011,479	3,047,643	9,222,498	5,816,751	2,829,595	1,548.7	241,233	101,480	139,753	34.7		37,133	23.8	93,248	41,161
Tennessee	8,492,619	4,302,991	13,431,633	8,492,543	3,901,956	491.0	307,094		307,094	5.3		46,727	5.9	76	47,214
Texas	24,244,024	12,291,253	37,580,691	23,907,965	11,760,024	2,779.8	478,512	284,494	183,387	.2	12,000	24,929	8.0	39,564	322,914
Utah	4,194,708	2,132,691	7,337,875	4,160,916	2,094,401	590.9	70,718	32,292	38,290					1,500	
Vermont	1,367,573	948,007	3,166,369	1,367,452	942,672	141.0								121	5,335
Virginia	7,416,757	3,765,387	11,651,923	7,293,588	3,410,217	607.9	267,062	37,959	211,441	34.1	50,946	59,917	7.4	34,263	83,813
Washington	6,115,867	3,106,412	9,400,613	6,112,042	3,025,446	302.7	46,596		46,596			14,823	.3	3,825	19,547
West Virginia	4,474,234	2,280,335	6,261,903	4,315,121	1,636,742	211.1	591,626	83,534	460,028	11.4		66,425	.7	75,579	117,140
Wisconsin	9,724,881	4,941,837	15,421,100	9,715,772	4,879,614	614.7	20,296		20,296			2,720		9,110	39,207
Wyoming	4,501,327	2,287,712	6,879,280	4,451,922	2,218,377	1,037.7	5,781	5,780		.3		33,085		43,625	36,250
District of Columbia	1,918,469	973,842	2,887,584	1,918,469	968,979	22.3									4,863
Hawaii	1,871,062	949,778	2,693,451	1,870,383	264,953	51.1	650,838		646,859	4.8		14,000		679	23,966
TOTALS	394,000,000	200,000,000	622,136,677	387,368,764	179,213,648	34,890.2	19,011,209	4,082,745	13,123,351	479.6	862,349	2,946,839	138.0	1,686,142	4,716,162

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AGRICULTURAL [illegible]
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PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 11 JANUARY 1937

MIXING OPERATIONS ON A [illegible] EXPERIMENTAL ROAD IN SOUTH CAROLINA

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

Volume 17, No. 11 January 1937

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EXPERIMENTAL BITUMINOUS TREATMENT OF SANDY-SOIL ROADS

REPORT ON EXPERIMENTS IN SOUTH CAROLINA

Reported by PAUL F. CRITZ, Associate Highway Engineer, United States Bureau of Public Roads
and H. L. SLIGH, Division Engineer, South Carolina State Highway Department

A BITUMINOUS experimental road was constructed in Horry County, S. C., in 1927. It is still in service, and the necessary maintenance has been such that the original construction has been preserved on about one-half of the project and the remainder has been modified only by the type of surface treatments applied.

The purpose of this experiment was to obtain information as to practicable methods of stabilizing the surfaces of roads built of the local materials characteristic of the southeastern coastal plain. Materials such as clays and mineral aggregates ordinarily considered satisfactory for stabilizing were not economically available and consequently bituminous materials were selected as the stabilizing agent.

At the time this road was built little information was available for the guidance of the engineers in the design of the sections and methods of construction. Since these experimental sections were built, however, considerable progress has been made in the field of low-cost bituminous road construction, and it is interesting to note that all of the materials and equipment and practically the same methods used in this experiment are in common use at the present time.

A better understanding of the methods and materials that give greater assurance of successful construction today has been made possible in a large measure by the information obtained from experimental roads. The fact that much of the road work done today by the State of South Carolina is based upon results obtained from this experiment indicates that it has been of considerable value.

ECONOMICAL METHOD OF STABILIZING SANDY SOILS NEEDED

Various methods of bituminous treatment to improve low-type roads have been employed by practically every State. Although many different materials and methods have been used, the improvements may be divided roughly into two classes: (1) The mat type of treatment, which is constructed not less than 1 inch thick; and (2) the surface-treatment type, in which the treatment is usually not more than 1 inch thick. Both types depend, as does any flexible surface, directly upon the base for support.

A wide variety of bituminous materials and aggregates have been used successfully for such work, and while different types of surfaces have resulted, there has been no special difficulty in providing a satisfactory surface for roads whose bases and subgrades were capable of supporting traffic.

For those localities where the roads were composed of loosely bound soil, such as sand or mixtures of sand, silt, and clay that were inherently weak, the problem of improvement was more difficult. Such a condition is found in the South Atlantic coastal area in general, and the eastern part of South Carolina in particular.

An appreciable mileage of the roads in this territory traverses relatively low, swampy areas that offer little opportunity for adequate drainage of the right-of-way because the ground-water level in many places is approximately at the elevation of the ground surface.

The locality these roads serve is mainly agricultural but pleasure resorts on the coast attract numbers of visitors. The traffic carried is variable in character and volume, ranging from fast-moving passenger cars to slow-moving, steel-tired vehicles carrying relatively heavy loads.

The soil composing these roads is predominantly sand containing clay and silt in varying proportions. As a rule no uniformity of composition exists, with the result that a satisfactory surface condition is the exception rather than the rule. The sand is composed of poorly graded, small-size particles. The clay possesses little binding power and slakes rapidly, breaking up in both wet and dry weather.

The combining of sand and clay produces a material which crumbles and becomes excessively dusty in dry weather. With continued dry weather traffic quickly cuts into the soil until the road becomes all but impassable. In wet weather water quickly softens the sand-clay and also causes the road to become almost impassable.

The stability of the surface, therefore, is as variable as the composition of the road material. On a given day the sandier portions might be extremely loose and difficult to travel over, while the portions containing some clay would be more stable but most likely would be very dusty. On the following day, if it had rained and the road was very moist, the sandier portions might present the better surface for traffic and the areas abounding in clay would be sloppy and rutted. Upon drying, these latter areas would regain some stability but the sandier portions would rapidly lose the stability provided by the moisture they had held temporarily. In all weather such surfaces are difficult to maintain in any condition approaching smoothness.

Obviously, the serviceability of a road of this kind is very limited and is not increased permanently by ordinary routine maintenance. In addition, the cost of maintenance under such conditions becomes an economic loss, especially when compared with the maintenance costs after the experimental surfaces were built. This later maintenance added to the permanent improvement of the road to such an extent that its cost in a large measure could be credited to betterment rather than to maintenance alone.

With a considerable mileage of such roads in need of immediate improvement, and with a relatively small amount of funds available for such work, South Carolina was confronted with a problem somewhat greater than existed in those States where the untreated roads were providing a satisfactory degree of serviceability and where it was necessary only to design a treatment that would either increase or make relatively permanent their present serviceability.

VARIOUS TARS AND ASPHALTS USED ON SECTIONS OF EXPERIMENT

Experience has shown the suitability of sand as road surfacing material when mixed with a satisfactory binder. It is also recognized that sand, properly confined, has high bearing value irrespective of its grading. Consequently, the problem in South Carolina was that of so treating the sand or mixture of sand, silt, and inferior clay that advantage might be taken of these inherent qualities.

To develop a satisfactory and economical method of improving these loosely bonded, sand-clay roads, the South Carolina State Highway Department, in cooperation with the Bureau of Public Roads, constructed an experimental highway during 1927. This highway, 20.6 miles in length and approximately 20 feet wide, extends north and west from the northwest city limits of Conway, S. C., to Galivants Ferry, S. C. The road on which the experimental sections were built was typical of those of the Atlantic coastal area and, in general, was quite unsatisfactory as a highway. Portions of it, passing through low, swampy areas, were poorly drained. Throughout its length there existed combinations of sand and clay ranging from practically pure sand to mixtures fairly high in clay. Its behavior in wet and dry weather was typical of the loosely bound, sand-clay roads of this area whose behavior has already been described.

Part of the project lies on United States Highway No. 701 and all of it lies on United States Highway No. 501, which is an arterial highway to the coast. During the spring and summer months it carries both heavy and light, fast-moving traffic. During the crop-marketing seasons the main traffic is heavily loaded vehicles, a fair portion of which is on narrow steel tires.

The experimental road was constructed during the period from May to October 1927 and was divided into eight experiments, some of which were subdivided into sections. Bituminous mats were constructed on all sections; some were designed to serve as wearing surfaces and others to serve as bases to which additional surface treatments were applied. Some of the sections were designed for machine maintenance and others for maintenance such as is ordinarily applied to macadam-like surfaces. One experimental section, a double-application surface treatment laid directly upon the sand-clay soil, was included for comparison with the other experimental sections of the project and also with similar treatments successfully applied in other parts of the State where the roadbed soil was believed more suitable for such treatment. Locations and descriptions of the experimental sections are shown in figures 1, 2, 3, and 4, which also show the extent and character of the various re-treatments applied.

Both hot- and cold-application tars and asphalts were used in construction. The cold-application tars had consistencies of 8–13, 18–25, and 25–35 specific viscosity, Engler, at 40° C., and the hot-application tar had a float of 155 at 32° C. The tar of 8–13 viscosity was used to prime an untreated base preceding surface treatment; the tar of 18–25 viscosity was used as a binder in the mixed base and for the surface enrichment of the mix without the addition of a mineral cover; and the tar of 25–35 viscosity and the hot tar were used as binders with stone cover in the surface treatment of mixed bases.

Two types of the cold-application asphaltic materials were used—rapid-curing and slow-curing materials. The former were various grades of asphalt cements ranging in penetration from 85 to 180, cut back to low viscosity with a heavy naphtha distillate. The latter were slow-curing, liquid asphaltic materials produced by different processes of refining. Both the rapid- and slow-curing asphaltic materials were used as binders in the mixed bases and for surface treatment of the mixed bases. When used for surface treatment, the rapid-curing cutbacks were used with mineral aggregate cover while the slow-curing oils were used only for surface enrichment with no mineral cover material.

The hot-application material was an asphaltic cement and was used only in surface treatment with stone cover. All asphaltic materials came from a single refinery as did all tar products used in the experiments. Analyses of these materials are given in tables 1 and 2, with the exception of the slow-curing oil E and the 25–35 viscosity tar, analyses for which are not available. Amounts used in each section are given in figures 1, 2, 3, and 4.

Crushed granite, pea gravel, sand, and treated material bladed from the mixed mats were used as cover materials. The mechanical analyses of the stone, gravel, and sand are given in table 3.

BITUMINOUS MATS BUILT USING EXISTING ROAD MATERIALS

Prior to actual construction of the experimental sections, the road had received the customary routine maintenance but little had been done in the way of permanent improvement. Drainage structures had been installed where there was considerable run-off and slight fills and cuts had been made. In general the grade, with respect to the adjoining area, was low in comparison with standards of drainage and grade in use at the present time.

The stationing begins at Conway and, for the purpose of this report, the road may be considered as extending east and west. References to "east" or the "east end of an experiment" are therefore to be taken to mean the beginning of the experimental section or the end nearest Conway.

The initial step in constructing the mixed base was preparation of the roadbed soil for treatment. This involved scarifying to the depth desired and pulverizing the loosened material with disk harrows and blade graders. On some sections the soil was already in such a loose condition that the blade grader, without scarifying, readily converted it into a well pulverized mass. As the material was loosened, it was moved to the roadside into windrows until the amount necessary for the required thickness of mat had been accumulated and was then spread over the full width of the road.

After the material was evenly distributed, usually in half-mile units, bituminous material was applied with 600-gallon pressure distributors. The total amount of bitumen was spread in two or more applications, and after each application a disc harrow turned the mixture of bitumen and soil. The object of this preliminary mixing was to prevent the early loss of light constituents of the bitumen, to protect passing traffic, and to prevent the accumulation of pools of bitumen in depressions and wheel tracks.

Final mixing was done by power-drawn graders which bladed the mixture back and forth across the road until it presented a homogeneous appearance. Because of varying composition and grading of the soil, some portions of the unit under construction might appear too lean or too rich. Additional bitumen or soil was worked into such portions until they appeared satis-

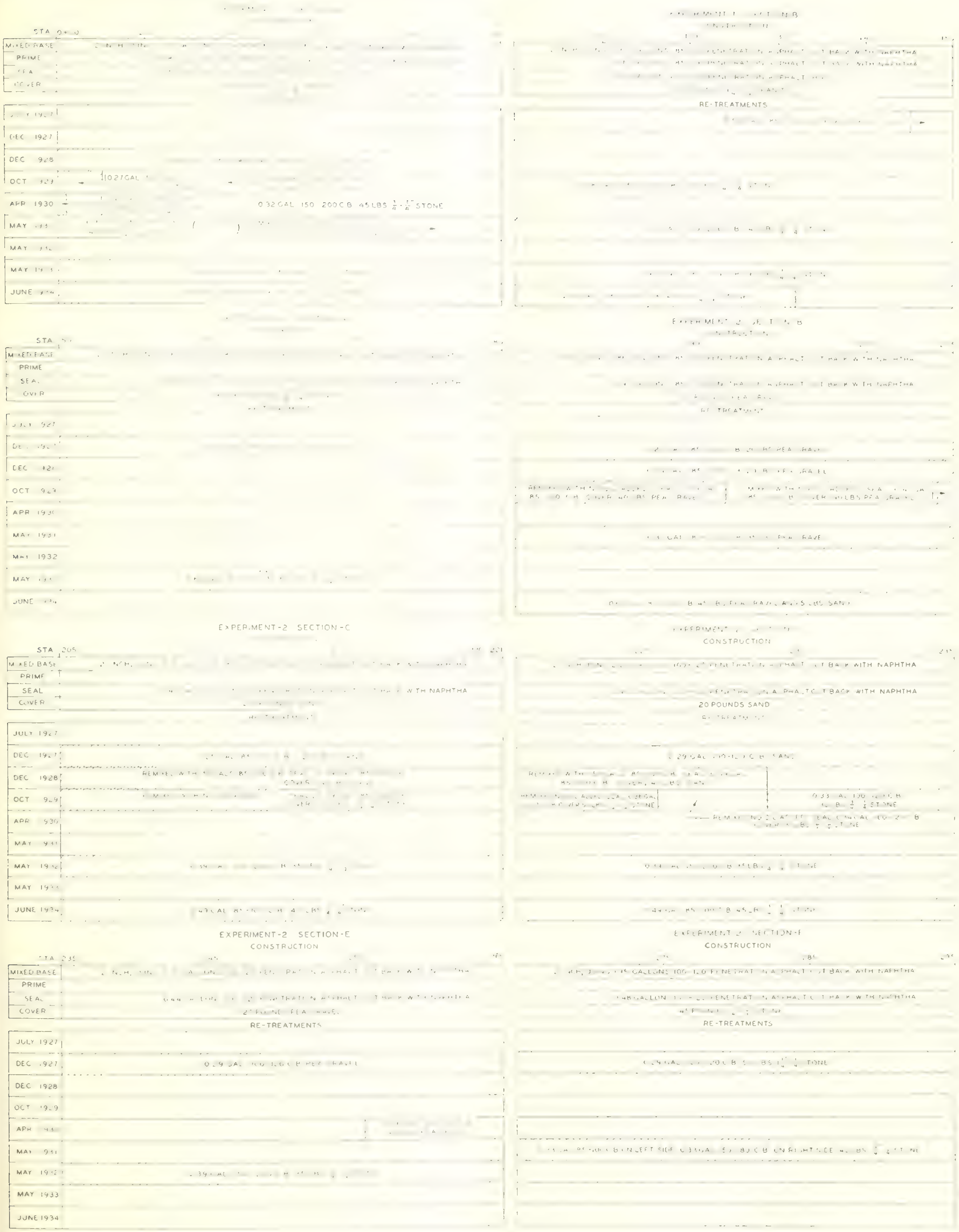

FIGURE 1.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 1 TO 2-F, INCLUSIVE.

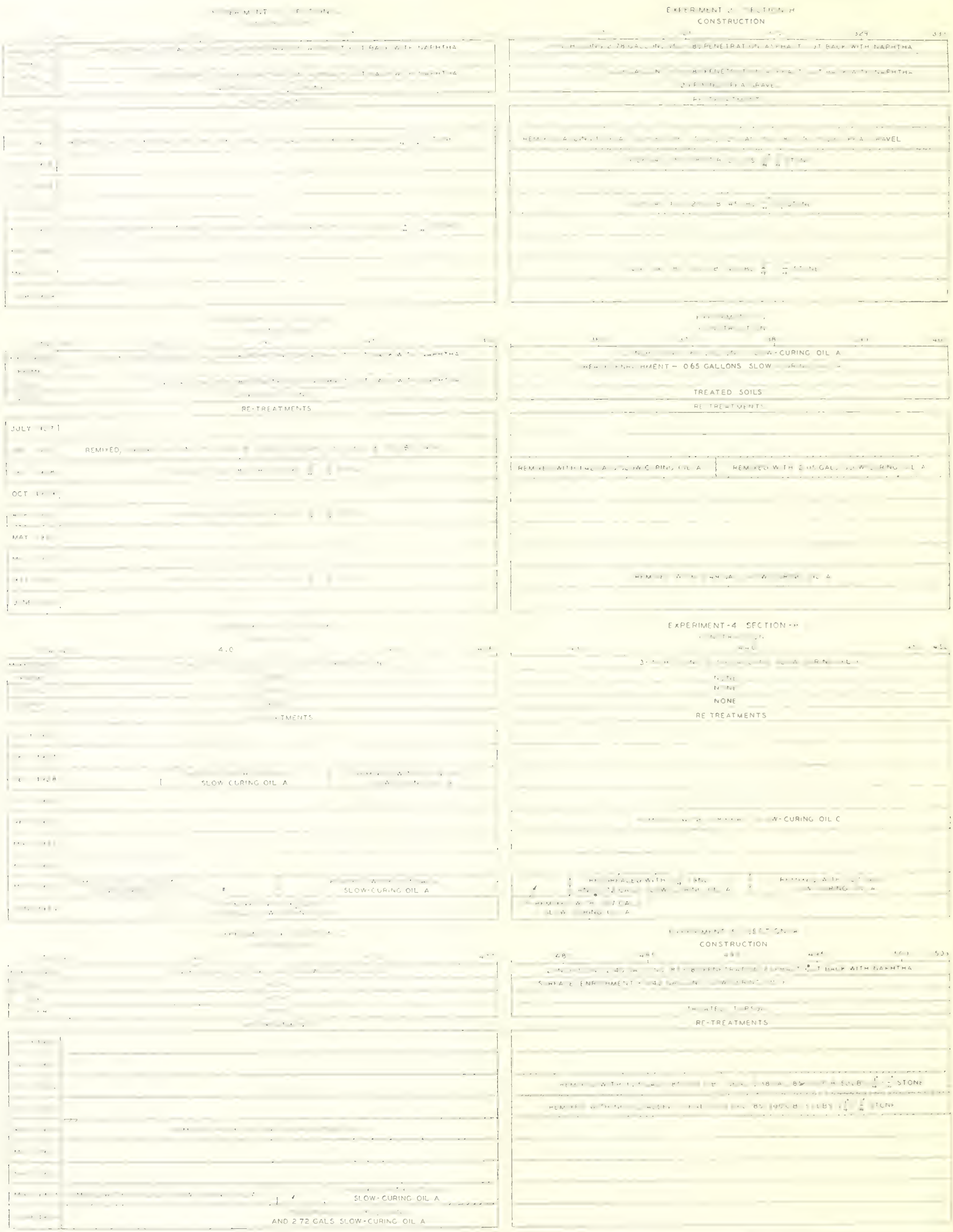

Figure 2.—Chart Showing Construction and Character of Re-treatments Applied to Experimental Sections 2-G to 5-A, Inclusive.

FIGURE 3.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 5-B TO 6-E, INCLUSIVE.

TABLE 1.—*Analyses of asphaltic materials used in construction and re-treatment*[1]

Type of material		Slow-curing oils							Asphalts of the penetration given, cut back with naphtha																Asphaltic cement
Designation		A[2]				B[3]	C[3]	D[3]	85-100 penetration							100-120 penetration		150-180 penetration					150-200 penetration		150-200 penetration
Laboratory number		29143	29147	30994	39068	29148	29743	29746	9 tests	29883	30993	32643	32645	35426	39069	29144	32644	29088	29145	29882	30992	35425	32646	35424	4 tests
Method of use		Construction	Construction	Re-treatment	Re-treatment	Construction	Construction	Construction	Construction	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Construction	Re-treatment	Construction	Construction	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Re-treatment	Construction
Date used		1927	1927	1928	1933	1927	1927	1927	1927	1927	1928	1929	1929	1931	1933	1927	1929	1927	1927	1927	1928	1931	1929	1931	1927
Sections on which used		3	3	3, 4-A	3, 4-A, B, C	4-A	4-B	4-C	1-B, 2-A, B, C, 5, 7, 8	1-B, 2-A, B, C, 8	2-B, C, D, 5-A	2-B, C	5-A, D, 7-B, C	2-B, F, G, 7-A, B, C, 8	1-A, B, 2-A, H, I, 5-B, C, D	2-D, E, F	2-D	1-A, 2-G, 5-B	2-H, I, 5-C	2-G, H, I	1-A, 2-H, I	2-F, G	1-A, B, 8	1-A, B	1-A, B, 7-A, B, 8
Purposes for which used		Mix and surface enrichment	Mix and surface enrichment	Remix	Remix	Mix	Mix	Mix	Mix, prime, and surface treatment	Surface treatment	Remix and surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment	Mix and surface treatment	Surface treatment	Mix and surface treatment	Mix and surface treatment	Remix and surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment	Surface treatment
Analyses																									
Specific gravity, 25°/25° C		0.942	0.941	0.972	1.012	1.025	1.028	0.974	0.941-0.950	0.949	0.938	0.953	0.944	0.955	0.948	0.957	0.949	0.952	0.956	0.959	0.938	0.949	0.949	0.950	1.01-1.03
Flash point	°C	110	115	125	127	105	127	132	25-52	29	29	32	30	27	29.5	50	31	54	35	30	28		29	23.2	225-275
Burning point	°C	150	165			145	149	172	27-60	40	30	36	35			60	37	65	40	50	30				
Specific viscosity, Engler, at 25° C		124	133			134			68-112	137						432		156	186	150					
Specific viscosity, Engler, at 40° C		33	40	138	69	36	41	48	25-48	36	39	88	52		88	105	72	45	57	45	40		56		
Specific viscosity, Engler, at 50° C				74						[4]3	21	52	31	70	44		37			[4]4	23	28	30	32	
Penetration, 25° C., 100 grams, 5 seconds																									167-186
Softening point	°C																								39-43
Loss, 163° C., 5 hours, 20 grams	percent	8.2	8.1	9.1	7.0	10.7	11.0	9.5	27.8-33.9	29.0	25.3	23.6	24.7	21.5	24.3	24.6	23.8	26.5	29.6	22.7	26.3	24.2	24.7	21.3	
Residue float at 32° C	seconds			115			157	53																	
Residue float at 50° C	seconds				22	25	57	24																	
Residue penetration at 25° C									56-98	51	75	75	69	66	51	77	77	79	58	140	62	102	95	102	
Loss, 163° C., 5 hours, 50 grams	percent	5.5	5.6	5.6	4.7	6.6	7.1	6.6	25.5-32.0	26.7	24.2	22.4	23.6	20.8	23.2	21.8	22.7	24.3	27.1	20.6	25.2	23.4	23.7	23.4	0.13-0.34
Residue float at 32° C	seconds						31	22																	
Residue float at 50° C	seconds				19		21	12																	
Residue penetration at 25° C									130-288	128	145	134	124	100	91	176	136	170	135	280	95	176		177	130-141
Bitumen soluble in CS_2	percent	99.76	100	100	99.94	100	99.78	99.81	99.87-100	99.86	100	99.85	99.90	99.91	99.86	100	99.87	100	100	99.85	100	99.86	99.85	99.85	99.91-99.80
Organic matter insoluble	percent	.00	0	0	.06	0	.18	.19	0-.10	.14	0	.14	.08	.06	.14	0	.07	0	0	.15	0	.13	.09	.14	0.09-0.20
Inorganic matter insoluble	percent	.24	0	0	.00	0	.04	.00	.0-.03	.00	0	.01	.02	.03	.00	0	.06	0	0	.00	0	.01	.06	.01	0.00-0.00
Bitumen insoluble in CCl_4	percent				.05																				
Bitumen insoluble in 86° B. naphtha	percent	5.5	5.3	12.8	8.4	13.9	14.2	10.6	16.0-18.4	19.7	15.8	15.1	16.0	17.8	17.0	18.3	15.2	17.4	20.4	18.7	17.6	14.4	13.9	13.8	20.3-25.5
Residue of 100 penetration	percent	59	58	70	61	66	69	61	66-72	71	75	76	75			75	76	73	71	75	73		74		97-99
Softening point of residue	°C	52	[illegible]	45	42	45	43	54	45-55	55	48	48	48			49	47	50	57	50	55		41		41-47
Ductility of residue at 25° C	centimeters	42	32	110+	110+	110+	60	8	14-110+	11	52	110+	110+			110+	110+	17	19	110+	9		110+		110+
Distillation by volume, D20-30 modified[5]:																									
Total distillate to 190° C. (374° F.)	percent											5.4	7.5				4.2						2.3		
Total distillate to 225° C. (437° F.)	percent											17.5	21.9				17.8						16.2		
Total distillate to 360° C. (680° F.)	percent											29.3	32.8				29.5						30.4		
Residue—Softening point	°C											45.8	49.6				45.0						41.8		
Residue—Penetration at 25° C.												90	98				98						183		
Distillation by volume, cooperative method[5]:																									
Total distallate to 437° F.	percent													14.2	20.0							16.6		16.8	
Total distallate to 600° F.	percent													23.7	26.5							26.1		26.3	
Total distillate to 680° F.	percent													25.0	28.5							28.5		28.4	
Residue—Penetration at 25° C.														96	85							169		166	
Residue—Ductility at 25° C.	centimeters													110+	110+							110+		110+	
Residue—Solubility in CS_2	percent													99.82	99.72							99.85		99.85	

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[1] Analyses of the 100-120 cut-back used in the 1927 re-treatments and of materials used in the re-treatments of 1930, 1932, and 1934 are not available, but were similar in characteristics to those used in former and later re-treatments as they were purchased under the same specifications. Analyses are not available for slow curing oil F, used in 1927 in surface enrichment of sections 5-A and 5-D during construction.

[2] Straight reduced.

[3] Pressure still or cracked asphaltic material.

[4] Specific viscosity, Engler, at 100° C.

[5] Thermometer bulb ¼ inch from bottom of flask. Residue poured immediately upon reaching maximum temperature.

FIGURE 4.—CHART SHOWING CONSTRUCTION AND CHARACTER OF RE-TREATMENTS APPLIED TO EXPERIMENTAL SECTIONS 7–A TO 8, INCLUSIVE.

TABLE 2.—*Analyses of tars used in construction and re-treatment*[1]

Method of use		Construction					Re-treatment
Date used		1927					1931
Material designation		8–13 viscosity	18–25 viscosity			Grade 2 (hot)	35–70 viscosity
Section and purpose for which used: Base mix		8	6–A, B, C, D, E				
Prime			6–C, D, E				
Surface treatment			6–A, B			6–D, E	
Re-treatment							6–A, B, C, D, E
Laboratory no.		29828	Minimum value	Maximum value	Average of 6	29753	36043
Analyses:							
Specific gravity, 25°/25° C.		1.136	[illegible]	1.165	[illegible]	1.206	1.151
Specific viscosity, Engler, at 40° C.		10.9	19.3	26.4	22.5		48.7
Float test at 32° C.	seconds					155	
Bitumen soluble in CS₂	percent	[illegible]	[illegible]	[illegible]	95.11	91.51	96.08
Organic matter insoluble	percent	5.80	2.66	[illegible]	3.17	8.49	3.69
Inorganic matter insoluble	percent	.07	0	.06	.02	0	.23
Water	percent	1.50	1.50	1.80	1.67	0	0
Distillation, A. S. T. M. D20–27T (by weight)—							
–170° C.	percent	[illegible]	.89	1.15	1.02	0	.37
170°–235° C.	percent	5.68	6.10	8.74	7.44	3.35	4.82
235°–270° C.	percent	13.30	[illegible]	11.16	10.64	[illegible]	10.54
270°–300° C.	percent	9.94	7.39	8.53	7.86	6.16	8.91
Residue	percent	69.12	71.44	[illegible]	72.61	83.95	75.20
Softening point of residue	° C.	39.6	45.8	49.9	47.6	49.5	37.4

[1] Data are not available for the tar of 25–35 viscosity used in surface-treating section 6–C.

TABLE 3.—*Mechanical analysis of mineral aggregates used as cover material*

Experiment no.	2	2	1, 2, 6, 7, 8	8
Material	Pea gravel	Sand	Granite	Granite
Laboratory no.	29558	29557	29630	29631
Retained on—	*Percent*	*Percent*	*Percent*	*Percent*
1-inch screen			4	
¾-inch screen			33	2
½-inch screen			73	35
⅜-inch screen	1		92	68
¼-inch screen	7		98	92
No. 10 sieve	41	4		
No. 20 sieve	61	29		
No. 30 sieve	70	52		
No. 40 sieve	81	74		
No. 50 sieve	87	79		
No. 80 sieve	92	85		
No. 100 sieve	93	88		
No. 200 sieve	96	94		

factory, after which the mixture was respread uniformly for compaction under traffic. Light blading was continued during compaction to obtain a smooth surface. Some difficulty was experienced in obtaining uniform distribution of traffic during this stage. Fast-moving vehicles tended to travel in the center only and slow-moving, steel-tired vehicles traveled along the edges where the wheels cut into the mixture instead of compacting it. Barriers first placed in the center of the road and then moved transversely at intervals successfully divided traffic into two lanes, causing more uniform compaction of each half of the road.

For the two sections designed for machine maintenance, this concluded the construction operation except for occasional light blading to retain surface smoothness. The analyses of the sand-clay and the resulting bituminous mixtures are given in tables 4 and 5.

AMOUNTS OF BITUMINOUS MATERIALS NEEDED IN MIXTURES WERE ESTIMATED

The remainder of the experimental sections were designed for patrol maintenance and were provided with wear-resisting surfaces obtained by two methods. One method was to enrich the surface portion of the mixed base by a light application of bitumen covered immediately with bituminous-treated soil previously windrowed to the sides of the road. The other method was to surface-treat the mixed base with bitumen and aggregate cover. This surface treatment was placed after allowing the base a period of time in which to become firm and smooth; the actual time varied from 3 or 4 days to a month. On those sections on which the bitumen used in the surface treatment was a cold-application, low-viscosity material, the bitumen was applied directly upon the smooth, compacted, mixed base and covered immediately with the selected mineral cover material. Where the binding material was a hot application or a fairly viscous cold-application bitumen such as the 25–35 viscosity tar, the mixed base was given a light prime with the same type of bituminous material that was used in the mixed base.

The mineral cover material was spread by hand from piles along the roadside and was hand broomed to obtain uniform distribution. Following its application the surfaces were rolled with 5-ton, three-wheel rollers.

After a few days under traffic, the completed sections varied in appearance, depending upon the air temperature and the materials used. All of the tar sections bled freely from the start and within a few days gave the appearance of having been in service for some time. The sections on which hot asphalt was used did not bleed so markedly and retained a loose, uncompacted appearance for a longer period. One exception was the first experiment, where less cover stone was used and so much bleeding occurred that additional cover stone was required to prevent the mat from picking up under traffic. The cold-application asphalt, which was a cut-back material, readily coated the stone cover which took on a dark appearance within a few hours.

TABLE 4.—*Analysis of road-bed soil used in mixed base construction and as the base for surface treatment of experiment 8. All are group A–2 or A–3 materials*

Experiment no.	Stations represented by sample	Laboratory no.	Mechanical analysis: Coarse sand 2.0–0.25 mm	Mechanical analysis: Fine sand 0.25–0.05 mm	Mechanical analysis: Silt 0.05–0.005 mm	Mechanical analysis: Clay 0.005 mm	Remarks
			Pct.	*Pct.*	*Pct.*	*Pct.*	
1-A	7–12	2884	17	70	6	7	Sandier portion of section.
	18	2885	14	65	9	12	Average composition.
1-B	115	3140	29	56	6	9	Do.
2-D	228	3143	21	52	8	19	Clay area.
2-F	290	3141	16	75	3	6	Sandy area.
2-G	310	3142	9	82	2	7	Do.
5-B	515–520	3515	6	86	2	6	Do.
	503–530	3517	5	88	2	5	Average composition.
5-C	530–556	3516	4	77	9	10	Do.
6-A	582–610	3684	5	75	8	12	Do.
6-B	610–636	3685	8	67	13	12	Do.
6-C	636–688	3686	5	66	16	13	Do.
6-D	688–742	3687	4	75	9	12	Do.
6-E	742–755	3676	4	80	8	8	Do.
	755–768	3677	4	80	6	10	Do.
	762–767	3568	8	70	8	14	Do.
	768–781	3678	4	82	6	8	Do.
	781–794	3679	4	84	5	7	Do.
7-A	794–807	3680	5	81	5	9	Do.
	807–820	3681	5	81	6	8	Do.
	820–833	3682	5	78	5	12	Do.
	833–846	3683	6	77	7	10	Do.
7-B	846–872	3567	6	76	4	14	Do.
	872–898	3688	4	86	5	5	Do.
	898–924	3689	4	85	4	7	Do.
	924–950	3566	8	77	5	10	Do.
7-C	950–975	3572	10	71	9	10	Do.
	975–1000	3573	13	69	6	12	Do.
8	1000–1025	3574	26	58	6	10	Do.
	1015–1020	3575	19	68	6	7	Do.
	1025–1050	3576	36	42	12	10	Do.
	1050–1087	3577	45	38	11	6	Do.
Average			11	73	7	9	

Experiment 8 was a double surface treatment applied directly to the untreated soil surface. The roadbed soil of this section, like that of the others, varied considerably in composition and degree of bond. Prior to applying the treatment the surface was swept to remove excess loose material. Depressions were filled with stone before the bitumen was applied. The prime was applied and allowed to dry for 4 to 6 days during which time traffic was detoured. The hot-application material was then spread, immediately covered with crushed stone, and lightly rolled.

In planning the experiments, the amounts of bituminous materials believed necessary were estimated, as little information upon which to design the mixtures was available at the time. During the initial construction it became apparent that the estimated quantities were too low and they were increased. The quantity used varied with the character of the soil encountered in the different sections. In sections 6–E and 7–A however, the amounts used were varied intentionally to study the effect of such variation on service behavior.

No particular difficulty was encountered in the mixing operation. All of the bituminous materials were

TABLE 5.—*Analyses of bituminous mixtures used as bases and surface mats, sampled during or immediately after construction*

Section	Stations represented	Laboratory no.	Bituminous material	Composition by weight: Bitumen	Passing ½ inch, retained ¼ inch	Passing ¼ inch, retained No. 10	Passing No. 10, retained No. 20	Passing No. 20, retained No. 30	Passing No. 30, retained No. 40	Passing No. 40, retained No. 50	Passing No. 50, retained No. 80	Passing No. 80, retained No. 100	Passing No. 100, retained No. 200	Passing No. 200	Appearance of the mixture
				Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	
1-A	70	29089	Asphalt, 150-180 penetration cut-back [1]	3.8	1.7	11.5	15.7	9.4	7.4	5.9	11.0	5.6	11.1	16.9	Poorly bonded.
1-B	115	29086	Asphalt, 85-100 penetration, cut-back [1]	4.0		.3	4.0	3.1	5.1	11.5	32.0	12.0	18.0	10.0	Do.
2-C	213	29836	----do	3.5	11.7	3.4	4.9	7.2	7.4	8.2	21.0	7.4	11.4	13.9	Do.
	205-220	29111	----do	3.8		2.7	6.4	3.8	6.5	9.8	29.0	11.0	12.8	14.2	Do.
2-D	228	29114	Asphalt, 100-120 penetration, cut-back [1]	3.8		1.2	3.2	3.3	5.7	9.1	29.7	14.0	17.9	12.1	Do.
2-G	300	29113	Asphalt, 150-180 penetration, cut-back [1]	2.8		1.1	1.7	1.2	1.7	2.1	32.0	31.0	14.0	12.4	Do.
2-H	327	29761	----do	4.2		.4	1.4	1.6	2.4	3.2	35.6	24.0	16.0	11.2	Do.
2-I	344	29112	----do	4.6		.4	2.2	2.3	3.3	3.3	13.9	20.7	39.9	9.6	Do.
4-A	400-426	29155	Slow-curing oil B [2]	7.1	2.0	1.6	2.0	1.2	1.2	1.6	22.8	19.6	28.4	12.5	Satisfactory.
4-B	426-452	29156	Slow-curing oil C [2]	7.6		.4	.8	1.2	2.0	2.4	33.6	21.6	21.2	9.2	Do.
5-B	515-520	29149	Asphalt, 85-100 penetration, cut-back	3.1		.6	.6	.4	.9	1.2	19.8	34.9	32.4	6.1	Poorly bonded.
	503-530	29150	----do	2.8		.8	1.2	.6	.8	1.4	23.1	24.9	34.0	10.4	Do.
5-C	530-556	29151	----do	4.9		2.8	2.8	1.4	1.4	1.2	21.0	11.4	30.7	22.4	Do.
6-A	582-610	29812	Tar, 18-25 specific viscosity [3]	3.2	.8	1.2	1.6	1.2	2.4	5.2	28.4	22.8	22.0	11.2	Do.
6-B	610-636	29811	----do	[illegible]	3.6	3.6	2.8	2.0	.6	2.4	44.4	4.0	21.2	4.2	Rich.
6-C	636-688	29810	----do	5.0	2.0	2.6	2.6	1.6	2.4	3.2	35.2	15.2	18.4	11.8	Well bonded.
6-D	688-712	29809	----do	5.1	2.0	1.4	1.6	1.6	2.8	3.2	24.8	18.8	27.6	11.1	Do.
6-F	742-755	29808	----do	[illegible]	.8	1.6	1.8	.2	2.0	2.4	19.0	[illegible]	27.2	10.2	Lean.
	755-768	29728	----do	[illegible]	[illegible]	1.5	2.0	.7	1.0	2.0	[illegible]	24.0	32.0	19.2	Well bonded.
	768-781	29807	----do	8.0	4.6	1.6	1.2	2.0	2.0	2.4	29.6	21.6	28.0	10.0	Rich.
	781-794	29806	----do	7.2	[illegible]	1.6	1.4	.8	.4	1.8	[illegible]	42.0	.8	2.6	Well bonded.
7-A	794-807	29762	Asphalt, 85-100 penetration, cut-back	[illegible]		1.6	1.6	.2	.4	1.8	[illegible]	26.0	[illegible]	10.4	Lean. [illegible]
	794-807	29772	----do	7.4	.4	.8	[illegible]	.2	.6	2.0	[illegible]	[illegible]	[illegible]	14.2	Well bonded [illegible]
	807-820	29763	----do	[illegible]		1.0	.8	.8	[illegible]	2.0	[illegible]	[illegible]	30.4	8.9	Lean. [illegible]
	807-820	29773	----do	6.7	.4	.4	[illegible]	[illegible]	.4	2.0	[illegible]	.8	[illegible]	[illegible]	Well bonded [illegible]
	820-833	29788	----do	[illegible]	.2	.8	1.4	.8	1.0	2.0	27.0	28.4	27.2	8.9	Well bonded.
	833-846	29789	----do	6.6	1.4	.8	1.6	.4	.4	2.0	[illegible]	42.0	8.4	[illegible]	Do.
7-B	846-872	29732	----do	5.7	.6	.4	.8	.4	.6	[illegible]	[illegible]	[illegible]	62.4	[illegible]	Do.
	872-898	29733	----do	6.7	2.4	2.2	2.2	.8	.8	1.4	14.8	20.0	[illegible]	11.7	Do.
	898-924	29770	----do	6.6	.4	1.4	1.4	.2	.4	1.6	10.0	22.0	40.8	12.2	Do.
	924-950	29771	----do	5.2	.4	.8	1.0	.8	.6	2.2	15.6	30.8	31.0	10.6	Do.
7-C	950-963	29790	----do	6.2	2.8	2.8	2.8	1.6	2.2	2.8	28.4	30.0	9.6	14.8	Do.
	963-975	29791	----do	[illegible]	1.0	2.0	2.6	1.6	2.2	2.8	19.2	38.0	11.2	13.1	Do.
	975-987	29786	----do	4.7	.4	2.6	4.0	2.4	2.8	3.6	54.0	[illegible]	10.6	13.3	Do.
	987-1000	29787	----do	4.6	8.8	4.0	3.6	2.2	2.8	3.6	16.0	16.4	22.6	15.2	Do.
			Range of values: Maximum	8.0	11.7	11.5	15.7	9.4	7.4	12.5	71.0	42.0	49.8	22.4	
			Range of values: Minimum	2.8	[illegible]	.3	.6	.4	.8	1.2	10.0	4.0	.8	2.6	
			Range of values: Average [4]	[illegible]	[illegible]	[illegible]	[illegible]	1.8	2.7	[illegible]	24.1	22.7	21.8	[illegible]	

[1] Asphalt of the penetration given was cut back with naphtha.

[2] Pressure still or cracked material.

[3] Engler specific viscosity at 40° C.

[4] Data for samples 29762 and 29763 excluded from averages.

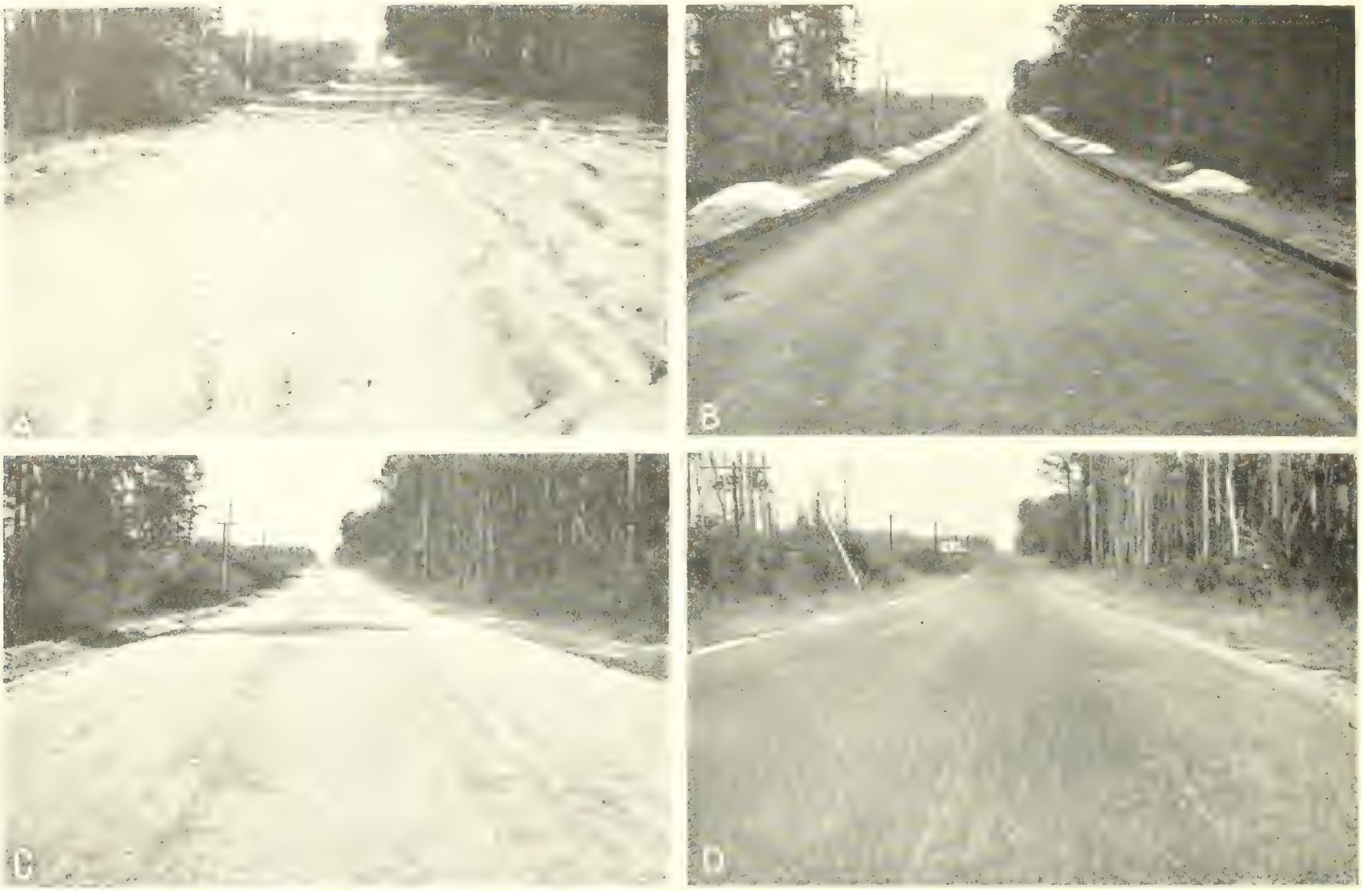

Figure 5.—Experiment 7-B at Station 898 During and After Construction. A, Loosened Roadbed Prior to Applying Bitumen; B, Mixed Base Completed and Ready for Surface Treatment; C, Surface Treatment Completed, Road Ready for Traffic; D, Appearance of Road 4 Years After Construction and 6 Months After the Only Surface Treatment It Has Received.

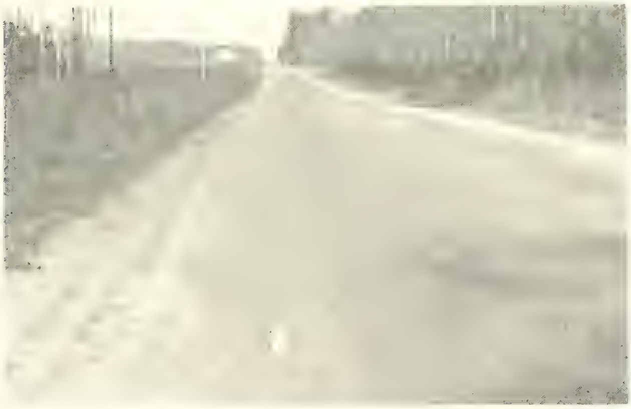

Figure 6.—Appearance of Experiment 7-B at Station 898 Seven Years After Construction and 3 Years After the Only Surface Treatment It Has Received.

warmed to obtain uniform distribution. Mixing was carried out promptly to insure thorough and uniform coating of all particles before the volatile constituents of the bitumen should be dissipated. However, no difficulty was experienced in this respect and ample time was available for mixing and spreading the mixture, even when rainy weather temporarily interrupted the mixing operation or made additional manipulation necessary for drying the mixture.

The methods of construction just described are in common usage today and need no further explanation. Figures 5 and 6, views taken at station 898 on experiment 7-B, illustrate the appearance of the road during its transition from an unimproved to an improved structure.

SURFACE ROUGHNESS CAUSED MAINLY BY UNSTABLE SUBGRADE

The costs of constructing the various experimental sections are given in table 6 together with the annual costs, which include re-treatments and maintenance of the bituminous mats but do not include any other maintenance costs.

The early behavior of the different experimental sections varied considerably as might be expected, but without exception, was a decided improvement over that of the untreated surface at its best. The dust nuisance was eliminated; traffic capacity was increased; riding qualities were greatly improved; there had been provided an all-weather surface which, with reasonable care, was satisfactorily maintained; and if necessary the road could have been economically bettered to meet increased demands, utilizing to a great extent the original investment.

Almost simultaneously with the completion of the sections, a number of failures demonstrated various weaknesses. The most outstanding unsatisfactory feature was surface roughness which, compared with that of the old road, was negligible but compared with that of the new surfaces in general, was very pronounced. While much of the roughness resulted from subgrade movement, other causes brought about the

TABLE 6.—*Cost of construction, re-treatments, and maintenance of the various experimental sections*

Section		Construction					Annual cost per square yard of re-treatments and maintenance of the bituminous surfaces only															
No.	Stations	Mixed base		Surface treatment		Cost per square yard	1927-28		1928-29		1929-30		1930-31		1931-32		1932-33		1933-34		Total	Average annual cost
		Thickness	Bituminous material	Bituminous material	Cover		Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance	Re-treatment	Maintenance		
		Inches				*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
1-A	0-100	2	Cut-back asphalt	Hot asphalt	1¼-¼-inch stone	33.76	---	5.12	6.24	2.08	11.36	2.49	9.85	2.09	---	1.30	14.11	3.54	11.12	4.50	73.80	10.36
1-B	100-150	2	do.	do.	do.	[1]32.22	---	4.82	---	3.23	[2]7.09	1.60	9.85	3.96	---	1.69	14.11	2.80	[2]7.11	5.13	61.39	8.69
2-A	150-180	2	do.	Cut-back asphalt	do.	35.11	4.25	1.41	---	1.88	---	1.21	---	2.09		.61	14.11	1.99	---	.91	28.46	4.09
2-B	180-205	2	do.	do.	Pea gravel	30.17	5.31	6.35	6.82	1.83	[2]7.00	1.13	8.65	1.00	---	---	---	---	15.31	21.17	74.57	10.65
2-C	205-221	2	do.	do.	Sand	34.52	4.53	6.86	26.66	2.73	16.91	3.05	---	.77	9.95	.89		1.04	14.73	16.88	105.00	15.00
2-D	221-235	2	do.	do.	do.	37.06	4.35	5.08	[2]15.24	2.06	12.74	2.51		1.04	9.95	2.49	---	---	14.73	4.29	74.48	10.64
2-E	235-265	2	do.	do.	Pea gravel	35.51	6.69	1.01	---	2.03	[2]2.81	1.69		1.96	9.95	1.86	---	.06	---	.74	28.80	4.11
2-F	265-295	2	do.	do.	1¼-¼-inch stone	37.06	13.29	2.28	---	.93	---	1.36	9.28	2.50	---	---	---	---			29.64	4.23
2-G	295-313	2	do.	do.	do.	45.46	31.85	3.16	---	2.67	---	2.01	9.28	1.98	---	---	---	---	---		50.95	7.28
2-H	313-333	2	do.	do.	Pea gravel	44.61	23.40	7.14	9.20	5.77	11.99	2.53		.46	---	.17	11.68	.18	---	.38	72.90	10.41
2-I	333-350	2	do.	do.	Sand	35.71	16.00	7.26	[2]8.56	4.56	11.97	1.93		.51		.40	11.68	.55	---	.45	63.65	9.09
3	350-400	2	Slow-curing oil A	Enriched with slow-curing oil A.	Treated soil	23.04	---	7.03	13.32	3.18	---	3.89	---	1.24	---	1.61	5.08	.09	---	.46	35.90	5.19
4-A	400-426	3	Slow-curing oil B	None	None	28.42		6.07	[2]6.57	4.43		3.57	---	1.92		1.79	13.42	.28	---	.84	38.89	5.62
4-B	426-452	3	Slow-curing oil C	None	None	24.39	---	7.33	---	6.16	9.33	6.38	---	1.52		1.46	13.42	.84	---	.90	47.34	6.84
4-C	452-477	3	Slow-curing oil D	None	None	28.50	---	7.01	1.22	4.33	10.37	8.62	---	1.93		.80	13.42	.38		.94	49.02	7.08
5-A	477-503	2	Cut-back asphalt	Enriched with slow-curing oil E.	Treated soil	33.70	---	3.72	30.45	3.49	16.13	2.71		1.19	---	.70	---	.64	---	.20	59.23	8.67
5-B	503-530	2	do.	Enriched with cut-back asphalt.	do.	30.95	---	3.24	---	2.41	---	3.36		1.17	---	1.45	11.39	1.74	---		24.56	3.58
5-C	530-556	3	do.	do.	do.	41.33	---	1.34	---	1.26	---	1.66		1.41		.71	10.59	.72	---	---	17.69	2.57
5-D	556-582	3	do.	Enriched with slow-curing oil E	do.	41.05	---	2.11	---	3.61	11.90	1.61	---	.56	---		10.59	.42			30.80	4.41
6-A	582-610	2	18-25 viscosity tar	Enriched with 18-25 viscosity tar	do.	49.36	---	2.58		3.38		.07	10.10	1.71				.12		.42	21.18	3.10
6-B	610-636	2	do.	do.	do.	63.94	---	4.50		2.82		2.75	10.23	3.33		.90		.16		3.78	28.51	4.28
6-C	636-688	2	do.	25-35 viscosity tar, cold.	1¼-¼-inch stone	63.29		2.51		2.97	---	1.01	11.22	1.14	---	.23	---	.06			18.94	[illegible]
6-D	688-742	2	do.	Hot tar	do.	62.31	---	2.31		2.42	---	.75	10.89	1.14	---	---	---	.06			17.57	2.51
6-E	742-794	2	do.	do.	do.	59.89	---	1.70	---	2.91	---	.93	10.10	2.73	---	---	---	.71	---	.18	19.26	2.84
7-A	794-846	2	Cut-back asphalt	Hot asphalt	do.	46.17	---	3.54		2.00	---	1.39	[2].38	2.61	9.87	1.37	---	.09	---	.22	21.47	3.21
7-B	846-950	2	do.	do.	do.	48.64		2.95		1.74	[2].97	.87	9.81	1.30	[2].05	---	---	.01		.02	17.72	2.63
7-C	950-1000	2	do.	Cut-back asphalt	do.	45.26		2.14		4.01	[2]4.65	1.72	9.81	1.98	---	---	---	.06		.28	24.65	3.68
8	1000-1087	---	Untreated sand-clay soil	Hot asphalt	do.	24.99	3.69	3.32	---	1.94	[2]8.76	1.36	[2]2.93	1.56	---	---		.07	---		23.63	3.54

---

[1] Includes re-treating last 500 feet of the section shortly after construction.

[2] Treatment applied to part of section only but cost is prorated over entire section.

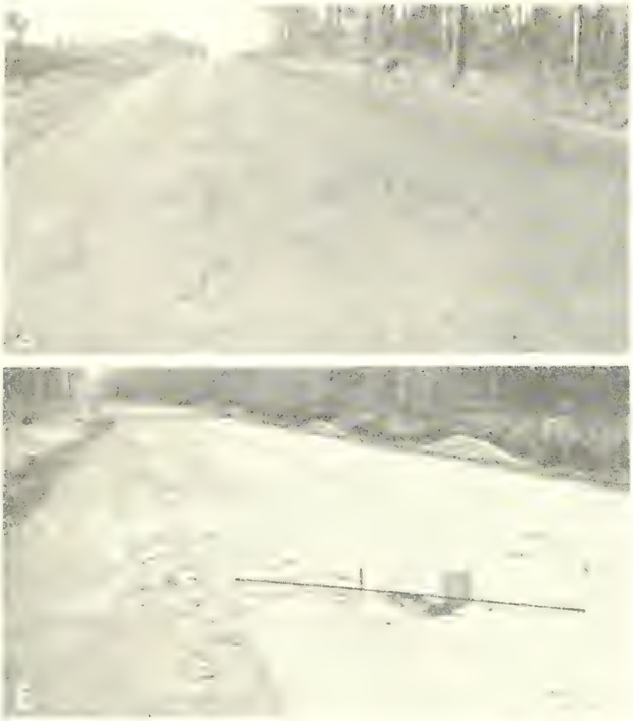

Figure 7.—A, Failure of Surface Treatment on Experiment 5–D, Which Was Constructed by Enriching the Top Portion of the Mixed Mat with Slow-Curing Oil. B, Appearance of Experiment 5–A Shortly After Construction. Its Surface, Which Was Enriched With Slow-Curing Oil, Scaled and Pot-Holed. The Base, Which Was Poorly Drained, Became Very Unstable.

same result. One of these was surface enrichment of the mixed mats designed to carry traffic without additional surface treatment or the use of coarse cover material. The upper portion of the mat peeled off to about the depth of enrichment, resulting in a rough, pot-holed surface. This condition, illustrated in figure 7, was eventually eliminated by a re-treatment in which a stone cover was used.

Another cause of roughness was the instability of the mixed base itself due to an improper combination of bituminous material and sand-clay. In some cases the amount of bituminous material used was apparently incorrect for an entire section; in others it was apparently correct for the major portion of the section but unsatisfactory for other portions because of variations in the sand-clay within the section. Tables 4, 5, and 7 indicate the wide variations in grading, not only among the sections but within a given section, which made it practically impossible to design a uniformly satisfactory mixture and would have made it impossible to have applied an empirical proportioning formula had such a formula been available at the time.

The bitumen content of the mixed bases, as determined by extraction tests, varied considerably. While the resulting mixtures are probably lean and might be unable to withstand traffic without a protective covering, increased stability has probably been obtained with the result that there has been less movement of the mat than would have occurred had the mixture been richer.

The most important factor contributing to roughness during most of the life of the road has been the subgrade, which is extremely variable in composition and, in some locations, is very poorly drained. Settlement occurred in some areas that had appeared stable prior to constructing the bituminous mats. Investigation disclosed that the subgrade in such areas was extremely wet and plastic while material less than a foot outside of the bituminous mat was firm and relatively dry. The mat apparently prevented surface evaporation and permitted the subgrade to acquire and retain sufficient moisture to destroy its stability. Obviously, the composition could not be changed after construction but considerable effort has been expended to provide artificial drainage. The groundwater level in many cases is so high that the maximum benefit derived by the construction of side ditches is to provide a relatively shallow depth of drained base which, because of its composition, is variable in load supporting capacity.

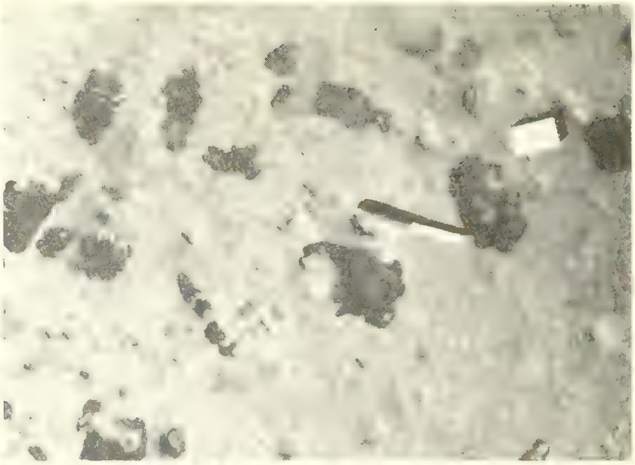

Figure 8.—Incipient Pot-Holing, Which Was Characteristic of Portions of Experiment 4.

Two other factors contributing to surface roughness were ordinary pot-holing and edge failure. The former, illustrated in figure 8, appeared in the sections designed for machine maintenance and was caused primarily by a lack of bituminous material. The latter type of failure appeared in varying degrees in most of the sections but was more pronounced on those in which fine grained or no cover materials were used. On such sections, steel-tired vehicles damaged the edges as illustrated in figure 9.

CONSTRUCTION AND RE-TREATMENT OF EACH EXPERIMENTAL SECTION DESCRIBED IN DETAIL

Another unsatisfactory and unsightly condition developed—bleeding or flushing of bitumen to the surface. This condition, which highway engineers are still striving to eliminate, appeared wherever the base became softened by an excess of bitumen, moisture, or clay, or a combination of these in an amount sufficient to permit the cover material to become embedded in the mixed bituminous base or in the sand-clay base. Where the bases were not thus softened and the cover material remained on the surface, bleeding did not occur.

Samples were taken 7 years after construction from areas representing various typical conditions. Analyses of subgrades and bituminous mats were made and are given in table 7 together with a description of the area represented at the time samples were taken.

Experiment 1, extending from station 0 to station 150, had a 2-inch mixed base of sand-clay and cut-back asphalt. It was primed with cut-back, sealed with hot asphalt, and covered with crushed stone.

This experimental section, which began at the northwest city limits of Conway and extended 3 miles northwest, was divided into sections A and B, which differed only in the cut-back asphalt used in the mixed base and prime application. On section A this bituminous material was a cut-back of 150 to 180 penetration asphalt and on section B a cut-back of 85 to 100 penetration asphalt was used.

As shown in table 4, samples of the sand-clay taken from various places on the experimental section showed considerable variation in composition. Many areas were low and poorly drained, as artificial drainage was not provided until later.

This was the first experimental section built and almost immediately after construction it was apparent that the bitumen content of the base was too low. Although surface-treated with hot asphalt and stone, the edges soon crumbled and broke badly, necessitating an additional treatment for a width of a few feet at the edges. Early movement of the mat resulted in a rough riding surface which has been, in general, characteristic of a considerable portion of this experimental section. To eliminate some of this roughness a 500-foot length at the west end of section B was given a re-treatment in July 1927. This treatment added to the surface smoothness considerably but shoving later developed at the extreme west end of the section due to unsatisfactory drainage conditions.

Since construction section A has received four complete and two partial re-treatments while section B was given two complete and two partial re-treatments exclusive of the 500-foot length re-treated as a part of its original construction. These re-treatments were applied primarily to seal cracks which had developed and to eliminate surface roughness.

During this same period considerable effort was made to provide drainage by the construction and maintenance of deep side ditches and by the installation of French drains. As a routine maintenance measure, badly shoved areas were repaired by removing the unstable material below the base, placing stone-filled trench drains, refilling with satisfactory base material such as cinders or coarse crushed stone, and then replacing the bituminous mixtures or using bituminous-coated stone. On many areas the result of such repair was a smooth surface which continued in good condition, but on other portions of the section identical repairs had to be made at intervals, especially on the low side of curved areas.

Prior to applying the re-treatment in May 1933, considerable effort had been made to remove all rough areas caused by subgrade movement. This treatment, consisting of 0.65 gallon of 85 to 100 cut-back and 60 pounds of ¾- to ¼-inch stone per square yard, was the heaviest treatment applied and contained sufficient materials to produce a mat of appreciable thickness. The section at first appeared to have been greatly improved by this treatment, but by the following spring those areas on which the subgrade had previously been troublesome again developed excessive roughness, shoved considerably, and required much additional maintenance. Figure 10 illustrates an excellent as well as an unsatisfactory area typical of the section in February 1934.

The slight variation in type of bituminous materials used in the mixed bases of sections A and B was at no time reflected in their behavior. There was no greater variation in behavior between the sections than within portions of each section. Construction and average annual maintenance costs of this experiment are shown in table 8.

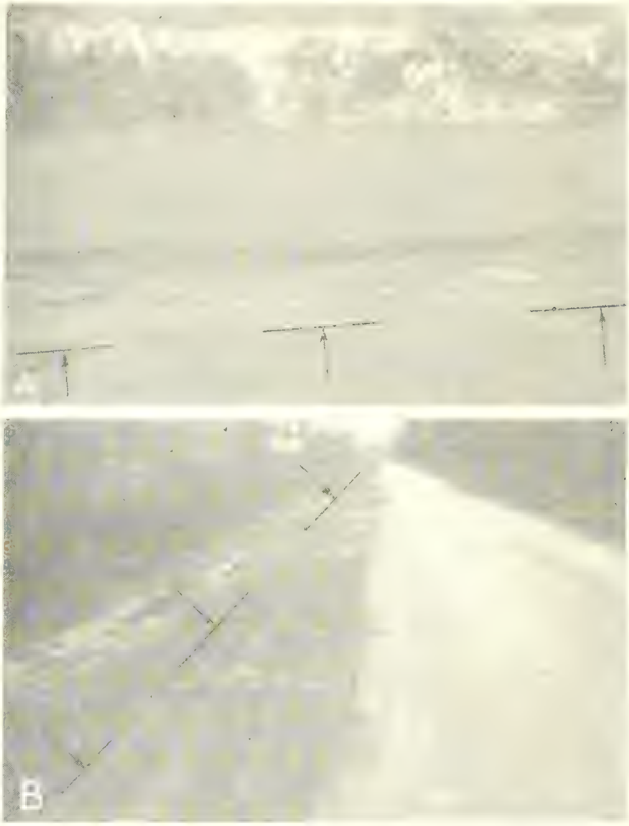

Figure 9.—Steel-Tired Vehicles Were Especially Destructive to the Edges of the Sections of Experiments 2 and 5, Which Had Not Received Adequate Surface Treatment. Arrows Indicate Original Edge of the Mat.

PERFORMANCE OF EXPERIMENT 2 AFFECTED BY SUBGRADE AND DRAINAGE CONDITIONS

Experiment 2, extending from station 150 to station 350, had a 2-inch mixed base of sand-clay and cut-back asphalt which was sealed with cut-back asphalt and covered with crushed stone, gravel, or sand.

Experiment 2 was divided into three groups of three sections each. They were constructed indentically except that the cut-back asphalt differed in each group and also that in each group one section was covered with 1¼- to ¼-inch crushed stone; one was covered with pea gravel; and one was covered with sand. The cut-backs used were made of 85 to 100, 100 to 120, and 150 to 180 penetration asphalts.

As in the case of experiment 1, subgrade and drainage conditions in this experimental section were exceedingly variable. Each section had sandy areas, areas high in clay content, poorly drained areas, and areas fairly well drained. Sections A, E, F, and G, however, had somewhat better natural drainage than the other five sections of this experiment.

Rainy weather encountered during base construction necessitated a considerable amount of manipulation for drying as well as for mixing the base materials. The seal treatment was applied directly to the mixed bases after they had been subjected to traffic for periods ranging from 4 to 30 days. On each section the bituminous

TABLE 7.—*Analyses of bituminous mats and subgrades from areas typical of the experimental road in 1934 (7 years after construction)*

BITUMINOUS MIXTURES

Experiment no.	1-A	1-B	3			4-B		4-C		5-C	6-A	6-B	7-C	8	
Sampled at station no.	63	145	373	363	398	440		453	457	543	585	639	981	1054	
Condition of wearing surface at location sampled	Mat almost gone; surrounding area has been heavily patched; slight fill through swampy section [1]	Very good and has always been so, free from cracking and raveling; drainage good [2]	Good, smooth, uncracked, on slight fill, drainage good [3]	Mat almost gone, bad area on curve, drainage poor, slight cut [4]	Smooth, cracked but not raveling; drainage fair	Rough, unstable in warm weather; old mat fairly firm; drainage poor		Fairly stable; some pitting due to clay balls; drainage fair	Very good; some hair-cracking but no raveling; drainage fair	Very good; mat stable; drainage good	Rough but stable; lies in a swampy section; natural drainage fair	Rough but stable; drainage is good	Very good, no cracking or raveling; drainage good	Very good, stable and free from cracking or raveling, drainage good	
														Left side	Right side
Laboratory no.			39359	39358	39357	39356		39355	39354	39362	39361	39360			
Original or remixed base or surface			Remixed 1933	Remixed 1933.	Remixed 1933.	Remixed 1933.		Remixed 1933.	Remixed 1933.	Original.	Original.	Original.			
Bituminous material used			Slow-curing oil	Slow-curing oil	Slow-curing oil.	Slow-curing oil.		Slow-curing oil.	Slow-curing oil.	Cutback	Tar	Tar			
Material represented—base or surface			Both	Both	Both	Both		Both	Both	Mixed base.	Mixed base.	Mixed base.			
Depth of mixed base or surface, inches			2¼-3	1 (approx.)	2⅜-2¾	4		3	4-4½	2¾-3¼	3	4-4¼			
Hubbard-Field stability at 77° F., pounds:															
Top inch [5]			1,620	1,730	2,910	[7]270		940	1,160	5,400	5,575	5,710			
Second inch [5]			1,550		830	[7]40		700	990	2,940	3,640	5,460			
Third inch [5]						[7]3,050			940			4,525			
Fourth inch [5]						[7]2,000			1,090						
Composite of above, remolded [5]			770	1,790	970	[6]0–[7]1,570		630	450	1,900	3,120	2,330			
Extraction and grading:						(6)	(7)								
Bitumen percent			7.1	6.8	9.2	9.2	9.3	7.0	10.2	7.7	7.0	8.7			
Passing ¼ inch, retained No. 10 percent			.1	.2		.1	.2	.1	.1	.5	.8	.1			
Passing No. 10, retained No. 20 percent			.8	.4	.6	.2	.5	.4	.3	.5	.4	.4			
Passing No. 20, retained No. 30 percent			3.1	1.5	1.2	.2	.8	.7	.9	.4	.4	1.4			
Passing No. 30, retained No. 40 percent			5.4	5.6	2.1	.9	1.9	1.8	1.5	1.2	.8	3.6			
Passing No. 40, retained No. 50 percent			5.4	5.9	2.9	1.4	3.2	2.7	2.1	1.7	1.7	4.6			
Passing No. 50, retained No. 80 percent			15.5	15.0	25.5	15.5	23.2	21.2	20.2	11.7	23.9	26.2			
Passing No. 80, retained No. 100 percent			16.5	16.8	21.6	33.5	20.6	25.7	23.6	22.9	23.1	23.2			
Passing No. 100, retained No. 200 percent			35.9	34.7	24.0	32.0	26.2	27.3	30.4	31.0	28.0	22.0			
Passing No. 200 do			10.2	13.1	12.9	7.0	14.1	10.1	10.7	22.4	13.9	9.8			

SUBGRADES

Laboratory no.	8157	8158	8159	8154	8155	8156	8153	8152	8151	[10] 6081	[10] 6082	8149	8148	6080	6067	8169	8147	8143	8144	8145	8146
Portion represented by sample inches	Top 6	6 to 12	12 to 18	Top 5	5 to 10	10 to 15	-----	-----	-----	Top 5	Next 5	-----	-----	-----	-----	-----	-----	Top 6	6 to 10	10 to 14	-----
Mechanical analysis:																					
Particles larger than 2.0 mm percent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	[illegible]	0	0	0	0	0
Coarse sand, 2.0-0.25 mm do	8	47	25	24	22	15	31	15	6	4	6	3	6	1	6	[illegible]	3	43	38	42	45
Fine sand, 0.25-0.05 mm do	26	21	33	44	42	27	52	58	60	48	71	65	77	36	72	[illegible]	69	15	20	23	34
Silt, 0.05-.005 mm do	26	11	17	19	18	15	3	11	10	10	9	7	5	37	5	[illegible]	13	18	20	15	8
Clay, smaller than 0.005 mm do	40	21	25	13	18	43	14	16	24	38	14	25	12	26	17	[illegible]	15	21	22	20	13
Colloids, smaller than 0.001 mm percent	32	17	21	10	12	38	12	14	18	32	10	18	10	11	11	[illegible]	9	14	10	10	9
Characteristics of material passing No. 40 sieve:																					
Percent passing	97	62	88	93	95	96	87	93	98			99	99				99	74	83	80	81
Liquid limit	41	33	32	14	15	47	19	20	27	42	17	27	18	28	26	16	17	33	35	22	[illegible]
Plasticity index	25	19	18	0	4	29	5	7	13	24	0	13	0	13	9	0	0	14	14	8	0
Shrinkage limit	13	14	15	---	14	14	-----	18	16	19	---	15	---	18	21	-----	---	23	25	17	---
Shrinkage ratio	1.9	1.9	1.9	---	1.9	1.8	---	1.7	1.8	1.7	----	1.8	---	1.8	1.7	----	----	1.6	1.5	1.8	---
Centrifuge moisture equivalent	26	22	21	11	19	26	10	14	13	24	8	14	6	21	14	[illegible]	9	26	28	17	7
Field moisture equivalent	24	19	21	14	13	27	18	19	19	26	17	19	21	19	20	20	19	25	27	17	[illegible]
Soil group	A-6	A-2 plastic	A-2 plastic	A-3	A-2 feebly plastic	A-6	A-2 plastic	A-2 plastic	A-2 plastic	A-6	A-3	A-2 plastic	A-3	A-4	A-2 plastic	A-3	A-3	A-2 plastic	A-2 plastic	A-2 plastic	[illegible]

---

[1] Condition shown in figure 10-B.

[2] Condition shown by figure 10-A.

[3] Condition shown by figures 14 and 15.

[4] Condition shown by figure 13.

[5] Field specimens tested as received.

[6] Data for new sand-oil mat built on old surface in 1935.

[7] Data for old surface prior to 1935.

[8] Under direct compression of 3,000 pounds per square inch.

[9] Mix heated in oven for 5 hours at 163° C. (325° F.) lost 1.42 percent by weight, equivalent to 18.44 percent of its bitumen content.

[10] Samples taken at station 456.

[11] Insufficient material.

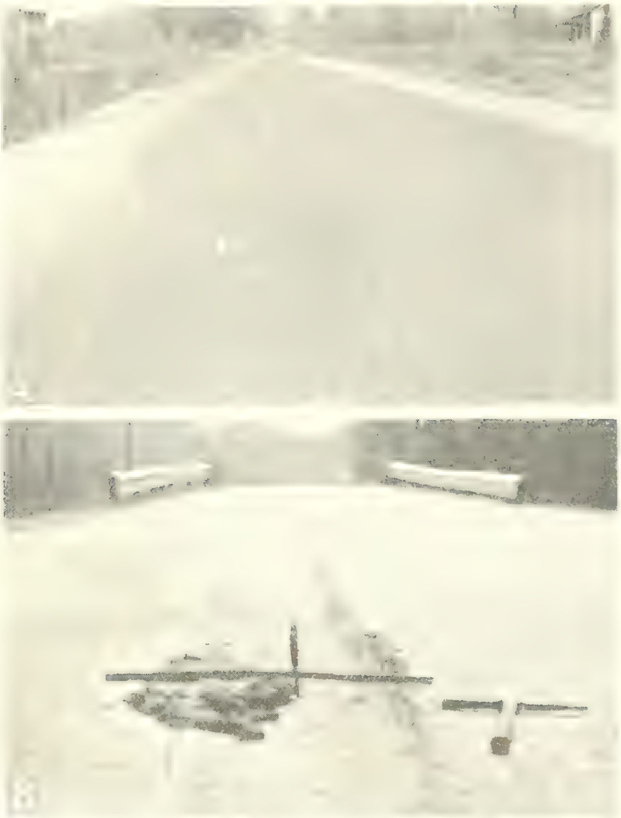

FIGURE 10.—TYPICAL VIEWS OF SATISFACTORY AND UNSATISFACTORY PORTIONS OF EXPERIMENT 1, SEVEN YEARS AFTER CONSTRUCTION. ANALYSES OF SUBGRADES FROM THESE AREAS ARE GIVEN IN TABLE 7. A, AT STATION 145 OF EXPERIMENT 1–B. B, AT STATION 63 OF EXPERIMENT 1–A; FAILURE CAUSED BY PLASTIC SUBGRADE.

TABLE 8.—*Construction and average annual maintenance costs per square yard for experiment 1*

Section	Construction costs				Average annual maintenance cost
	Bituminous material	Stone cover	Labor and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	17.16	7.61	8.99	33.76	10.36
B	16.96	7.65	7.61	32.22	8.69

material used in the seal was the same as that used in the mixed base. Crushed granite, $1\frac{1}{4}$- to $\frac{1}{4}$-inch, was the cover material for sections A, F, and G; pea gravel was used on sections B, E, and H; and a local sand was used on sections C, D, and I.

One month after construction, section H had broken up to such an extent that it was necessary to remix it with additional bitumen and reseal it. Other sections of experiment 2 exhibited various defects which were not of sufficient proportion to warrant reconstruction.

In December 1927 experiment 2 was re-treated with the same types of bituminous and cover materials that were used in construction except that sand instead of stone cover was used on section A. In addition, sections G, H, and I were remixed with additional bituminous material prior to applying the re-treatment. Since 1927 the stone-covered sections have received only one re-treatment: Section A in 1933; and sections F and G in 1931.

Of the gravel-covered sections (B, E, and H) section E continued the most satisfactory, the re-treatments having been limited to a treatment of the last 950 feet of the section in 1930 and to the entire section in 1932. Section H was re-treated in 1928, 1930, and 1933 and in each treatment stone cover was used instead of pea gravel. Section B, still maintained as a pea-gravel covered section, was re-treated in its entirety in 1928, 1931, and 1934 and approximately half its area was remixed and re-treated in 1929.

The sand-covered sections C, D, and I soon became rough, pot-holed, and unstable, and their edges raveled under steel-tired vehicles. Sand was used as the cover material in the re-treatment of the entire experiment in 1927 and to cover section C and part of section D, after they were remixed in 1928. The recurrence of surface failures, however, led to the substitution of stone as the cover material in the subsequent re-treatments applied to sections C and D in 1929, 1932, and 1934 and to section I in 1928, 1930, and 1933.

Figures 9–B and 11–A illustrate the unsatisfactory surface conditions that existed on these sections during the period when the wearing surfaces were composed of sand and cold-application bitumen. They also illustrate the unsatisfactory drainage conditions existing at the time the sections were built and during their early life.

With the substitution of stone as the cover material and with the construction of side ditches and lateral drains, the unsatisfactory behavior was largely eliminated and the service behavior of the sections became comparable to that of the other sections of this experiment.

Construction and maintenance costs of this experiment per square yard are shown in table 9.

TABLE 9.—*Construction and average annual maintenance costs per square yard for experiment 2*

Section	Cover	Construction costs				Average annual maintenance costs
		Bituminous material	Cover material	Labor, supplies and equipment	Total	
		Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	Stone	23.18	6.72	5.21	35.11	4.09
B	Gravel	21.83	2.59	5.75	30.17	10.65
C	Sand	24.82	.20	9.50	34.52	15.00
D	do	25.22	.22	11.62	37.06	10.64
E	Gravel	27.26	2.59	5.66	35.51	4.11
F	Stone	23.57	6.72	6.77	37.06	4.23
G	do	26.19	7.45	11.82	45.46	7.28
H	Gravel	30.17	[1] 4.55	9.89	44.61	10.41
I	Sand	23.28	.18	12.25	35.71	9.09

[1] Includes 2 applications of gravel cover, the first of which was incorporated into the mixture when the section was reconstructed 1 month after original construction.

SURFACE CRACKS DID NOT IMPAIR EXPERIMENT 3

Experiment 3, extending from station 350 to station 400, had a 2-inch mixed base of sand-clay and slow-curing oil A. Its surface was enriched with oil A and covered with bitumen-coated sand-clay.

This experiment, approximately 1 mile in length, was one of the sections in which a slow-curing oil was used and was designed for machine maintenance.

On this experiment the subgrade and drainage were somewhat better than on the two preceding experimental sections, except for a short portion, in the vicinity of station 365, which lay in a swampy area.

During construction a severe storm interrupted the mixing operation and the heavy rainfall washed a considerable but undetermined amount of oil into the side ditches. When mixing had been completed the surface did not bond and the quantity of oil, with which it was planned to enrich the top portion of the mat by penetration, was increased to 0.65 gallon per square yard. This application was covered with oil-treated sand-clay. Except for occasional light blading to retain surface smoothness, this completed the construction of the section.

In general, the behavior of experiment 3 during the period covered by this report has been good. It has been scarified and remixed three times since construction. In two of these remixing operations, those of 1928 and 1933, oil was added, but the remixing in 1929 was done primarily to eliminate instability which had developed in the bituminous mat due to excess moisture.

The section was similar to a sheet asphalt pavement in texture but its color was brown and it had acquired a somewhat glazed surface under traffic. The major portion of this experiment remained fairly smooth but three relatively small areas continued rough and spongy as if excessively rich in bitumen. However, an unstable base, poor drainage, and the presence of water was the cause of instability rather than excessive bitumen. Practically all of the experimental section was covered with fine hair cracks throughout most of its life. Except in the areas more greatly affected by moisture, this cracking apparently had not seriously affected the behavior of the section. Figure 11 B illustrates the most advanced stage of cracking which, although unsightly, did not progress to the stage of disintegration.

Although designed for machine maintenance, the surface eventually crusted so that dragging for surface smoothness was not practical and depressions were usually filled with premixed material. High spots were easily cut with a blade but the material so removed was whipped from the surface by traffic rather than compacted into the low spots.

The cost per square yard of constructing this experiment was as follows:

	Cents
Bituminous material	17. 78
Labor, supplies, and equipment	5. 26
Total	23. 04

The average annual maintenance cost was 5.19 cents per square yard.

In the period subsequent to that covered by this report, an unsatisfactory condition developed that seriously affected the service record of experiment 3. The surface glaze, previously referred to, became very pronounced in the intervals during which the surface was not disturbed by machining or remixing. The glazed surface became very slippery in wet weather and so dangerous to traffic that the highway department, in 1935, applied a surface treatment of cut-back asphalt and stone.

ORIGINAL CONSTRUCTION ON EXPERIMENT 4 BECAME HARD AND BRITTLE, REQUIRING RE-TREATMENT

Experiment 4, extending from station 400 to station 477, had a 3-inch mixed mat of sand-clay and slow-curing oils, B, C, and D.

Experiment 4 also was designed for machine maintenance and its construction was similar to that of experiment 3 except that all of the bitumen applied was mixed with sand-clay to form the mat. The experiment was divided into three sections which differed only in the kind of oil used.

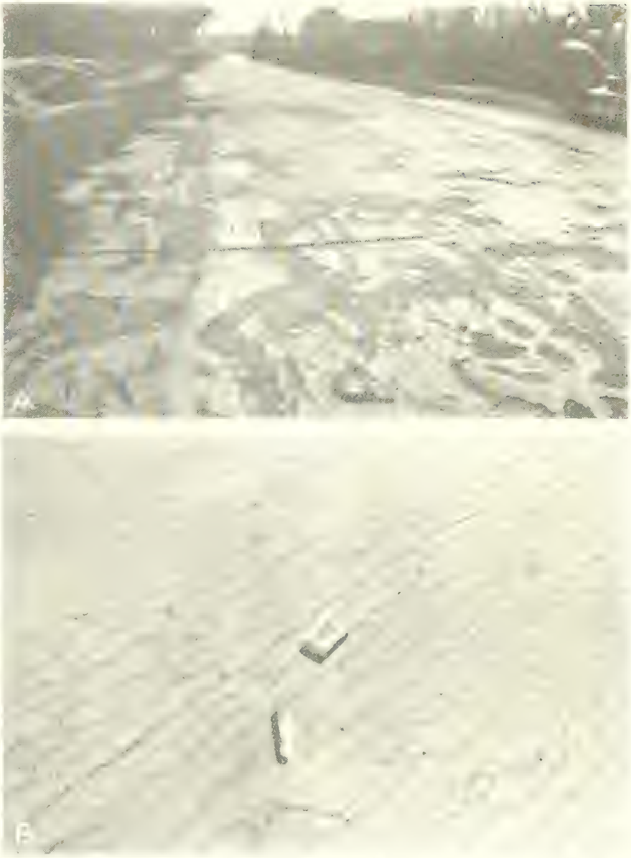

FIGURE 11. INADEQUATE DRAINAGE CONTRIBUTED TO BASE FAILURE ON THESE EXPERIMENTAL SECTIONS. A, BOTH BASE AND SURFACE FAILED ON EXPERIMENT 2, SECTIONS C AND D. SAND WAS USED WITH A COLD-APPLICATION MATERIAL FOR SURFACE TREATMENT, RESULTING IN A RICH, PLASTIC MIXTURE. B, BADLY CRACKED AREA ON EXPERIMENT 3, CAUSED BY A PLASTIC SUBGRADE.

Subgrade and drainage conditions were quite variable in each of the sections but were somewhat better in section C than in sections A and B. Portions of sections A and B lay in low, swampy areas where the ground water level was very close to the elevation of the road surface. The character of the sand-clay was exceedingly variable. At some time prior to construction of the experimental sections, clay had been used where needed to fill holes. Apparently, no attempt had been made to mix the clay with the material already in the road, consequently the base and the sand-clay in the mixed mat ranged from very sandy mixtures to mixtures high in clay content. This was especially true of the west portion of section B and the east portion of section C.

When the sections had been laid down and compacted under traffic, they were similar in appearance to experiment 3 except that the glaze was more pronounced and, in general, they appeared harder and less malleable. Material loosened by dragging or light blading did not readily rebond but was dissipated by traffic.

The first remixing was done to section A in 1928. The east 600 feet were not remixed, as that portion of the section was in excellent condition. The next 1,000-foot portion, which had become rutted through the swampy area and also was badly pot-holed elsewhere, was scarified and remixed with approximately 1 gallon of oil A per square yard. The remaining 1,000-foot portion on the west end of the section appeared hard, firm, and only slightly pot-holed but had a decided tendency to dust under traffic. It was decided to experiment by lightly scarifying the top portion of this area, and adding about one-half gallon of oil A per square yard, which, with a small amount of sand-clay brought in from the sides, formed a thin new wearing surface for the old mat. The plan was successful as the new material bonded readily to the old mat and dusting under traffic stopped.

Sections B and C were first remixed in 1930 with approximately 0.8 gallon of oils C and D per square yard, respectively, the same oils as were used in the original construction.

All three sections were again treated in 1933. It was attempted in this treatment to raise the grade through the swamp on section A and to elevate the outside edges of two sharp curves on sections B and C. On section A the additional sand and oil added to raise the grade were mixed with the old mat which had been scarified. The curves on sections B and C were elevated by building a new mat on top of the old one. The remaining portions of this experiment were remixed with additional oil.

The remixing operations revealed considerable differences in the character of the mixture on experiment 3 as compared with experiment 4. The mat on experiment 4 broke up readily and required only a small amount of harrowing and blading to reduce it to a uniformly fine mass which did not appear at all "alive". The mat of experiment 3, on the other hand, was malleable and in spite of considerable harrowing and blading did not break down into a uniformly divided condition. Under the traffic that passed while the work was being done the pulverized material on experiment 4 compacted but did not rebond, while that on experiment 3 not only compacted but rebonded to such an extent that additional manipulation was necessary before the oil was added. Upon adding the oil and remixing, however, the scarified portions of experiment 4, in general, compacted and bonded very much better than those areas on which a new mix was built upon the old mat.

On those portions of the experimental section previously referred to as containing considerable clay, it was noted that within a few days after the mix had been relaid small areas in the center of the road were cracked and raveling. These spots and the surrounding areas were immediately remixed and relaid, and within 3 hours under traffic the same undesirable features reappeared in the same locations. Upon removing the mix a 2-inch layer of wet, sticky clay was found between the bituminous mat and the sandy base. This layer of clay was removed from portions of these areas and the bituminous mix replaced. No cracking or raveling reappeared and the small areas thus repaired remained in excellent condition. The particular locations of these areas of failure, directly under the area of concentrated traffic, suggest the possibility of movement or flow of clay under the vibrating action of traffic. It appeared most practical not to attempt to remove all of the heavy clay deposits from the base because of the irregularity of their location but to make repairs as a maintenance measure when and where necessary.

The construction and average annual maintenance costs for each of the sections of this experiment are given in table 10.

TABLE 10.—*Construction and average annual maintenance costs per square yard for experiment 4*

Section	Construction costs			Average annual maintenance costs
	Bituminous material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*
A	23.78	4.64	28.42	5.62
B	19.75	4.64	24.39	6.84
C	23.86	4.64	28.50	7.08

A slippery surface developed on experiment 4 similar to that which developed on experiment 3, and at the same time. The same remedial measures were applied to both experimental sections at the same time.

STEEL-TIRED VEHICLES WERE DESTRUCTIVE TO EDGES OF EXPERIMENT 5

Experiment 5, extending from station 477 to station 582, had 2- and 3-inch mixed bases of sand-clay and cut-back asphalt. The surface was enriched with slow-curing oil E and cutbacks, and was covered with bituminous-treated soil.

This experiment comprised four sections—A, B, C, and D. The mixed bases of sections A and B were 2 inches thick and those of sections C and D were 3 inches thick.

The bases were mixed with 85 to 100 penetration cut-back asphalt, spread and compacted by traffic. A small amount of the mixed base was windrowed to the sides to be respread after the surface enrichment application had been made. The bituminous material used for this purpose on sections A and D was the slow-curing oil E, similar to that used in experiment 4, and on sections B and C it was a 150 to 180 penetration cut-back asphalt. Approximately 0.4 gallon per square yard was used on each of the sections.

The subgrade and drainage of this experiment, while varying somewhat, were better than on the preceding experimental sections. With the exception of part of section A, good natural drainage and fairly stable subgrade were characteristic of this experimental section. The exception was approximately the center third of section A, which lay in low swampy area very difficult to drain. Side ditches were of no great benefit as they quickly filled with sand and silt and permitted surface water to reach almost to the bituminous mat. This condition is illustrated in figure 7–B. About 1930, however, the entire swampy area was drained and the ground-water level lowered so that recently there have been no failures directly attributable to unstable subgrade.

The sections immediately after construction resembled a sheet asphalt pavement, with sections B and C appearing more substantial than sections A and D. The surfaces of sections A and D scaled and pot holed badly, section D more so than A. There appeared to be little bond between the enriched surface portion and the relatively lean base, as the surface shoved, peeled, and pot-holed to the approximate depth of enrichment. This type of failure is illustrated in figure 7–A.

Sections B and C were similar in appearance and behavior. While pot-holing and surface roughness were far less pronounced than on sections A and D, the edges of the mats did suffer severely under steel-tired vehicles that cut through the mix as illustrated in figure 9–A. Considerable early maintenance, consisting of placing new mixture along the edges, was required to maintain the original road width.

Section A developed roughness, pot-holed, and became unstable due to what was thought to be excessive richness. By December 1928 it was in such unsatisfactory condition that reconstruction was deemed advisable. When the section had been scarified and pulverized it was evident that the apparent richness was caused primarily by moisture and not by excess bitumen. One and one-quarter gallons per square yard of 85 to 100 penetration cut-back asphalt were added and the section was remixed. After compaction under traffic the surface was sealed with 0.38 gallon per square yard of the same type of cut back, covered with 50 pounds per square yard of 1¼- to ¼-inch stone, and then rolled. Its condition prior to scarifying and re-treating is illustrated in figure 7–B.

By the fall of 1929 the section had again become unstable and extremely rough, and again it was scarified and remixed, but without adding bitumen. It was then resealed with 0.38 gallon of 85 to 100 penetration cut-back asphalt and 50 pounds of 1¼- to ¼-inch stone per square yard and rolled. About this time a drainage ditch, constructed through the swamp, removed the water from the surrounding area and, with the side ditches then capable of handling surface water, the subgrade became stable and has so remained. Except for a rather lean surface appearance, the section in July 1934 was in better condition than at any previous time.

Section D, which was identical with section A except that its bituminous base was 3 inches thick, was retreated in the fall of 1929 to eliminate excessive roughness and to preserve the mixed base. The treatment consisted of applying 0.39 gallon of 85 to 100 cut-back asphalt and a cover of 40 pounds of ¾- to ¼-inch stone per square yard. This treatment greatly benefited the section by eliminating most of the roughness and scaling of the mat.

Sections B and C continued in fair condition except for the roughness and edge failure already noted. Maintenance of these two sections consisted mainly of building up the edges and removing depressions, using for this purpose a mixture of sand-clay and cut-back asphalt. In May 1933 they were in fair condition for the surface treatment that was applied to them and to section D. The treatment consisted of 0.46 gallon of 85 to 100 penetration cut-back asphalt and 40 pounds of ¾- to ¼-inch stone per square yard.

The construction and average annual maintenance costs per square yard for this experiment are given in table 11.

Table 11.—*Construction and average annual maintenance costs per square yard for experiment 5*

Section	Construction costs			Average annual maintenance costs
	Bituminous material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*
A	26.60	7.10	33.70	8.67
B	25.22	5.73	30.95	3.58
C	32.20	9.13	41.33	2.57
D	32.51	8.54	41.05	4.51

2 GALLONS OF TAR PER SQUARE YARD FOUND TO GIVE STABLE MIXTURE

Experiment 6, extending from station 582 to station 794, had 2- and 3-inch mixed bases of sand-clay and tar. The bases were primed with tar, surface-treated with hot and cold-application tars, and covered with tar-treated sand-clay or with crushed stone.

This experiment included five sections in which the bases were sand-clay mixed with tar of 18 to 25 specific viscosity at 40° C. The bases were 2 inches in thickness except that of section B which was 3 inches.

Sections A and B were surface-treated by the enrichment method similar to that employed on experiment 5, using for this purpose the 18 to 25 viscosity tar and treated sand-clay. The surface-treatment of section C consisted of an application of tar of 25 to 35 specific viscosity at 40° C., applied cold, and a cover of 1¼- to ¼-inch stone. Sections D and E were surface-treated in the same manner except that the bituminous material was a hot-application tar.

Experiment 6 lies entirely in rolling country and has good natural drainage except for about 200 feet of section B which borders a swampy area. The subgrade varied considerably in composition, the west portion of section A, the east and west ends of section B, and the east half of section C appearing to have more clay than the remainder of the experimental section. This was quite noticeable both in mixing and in the appearance of the finished mixture. Sections D and E appeared to contain little clay as the untreated material pulverized easily before the tar was applied, coated readily, and was uniform and free from uncoated clay balls when mixing was completed. Sections A, B, and C, on the other hand, required more than the usual amount of mixing, in spite of which a uniform mix was not obtained owing to the presence of many uncoated clay balls.

During the construction of sections A, B, C, and D, mixing was interrupted by rain and additional blading was necessary to dry the mixture. Under traffic the mixture, on those areas that had appeared high in clay content, did not compact into a dense uniform mat but into stratified layers, the surface being considerably marked by irregular vertical cracks.

Sections A and B, for which surface-enrichment was planned, began to dust under traffic before they had compacted. An attempt to enrich the surface of section A while in a dusty condition proved unsuccessful, so the two sections were remixed and relaid. They were then given the surface-enrichment application immediately after initial compaction had been obtained and before dusting could start—a period of about 24 hours.

The enrichment application, amounting to 0.27 gallon per square yard for section A and 0.28 gallon per square yard for section B, was lightly covered with tar-treated sand-clay which had been previously bladed from the mat and windrowed at the sides for this purpose.

Sections C and D were given a light application of 18 to 25 viscosity tar after they had been compacted and before the surface treatment was applied.

Section E varied from the other sections of experiment 6 in that different amounts of tar were used in four portions of the base, to determine, if possible, the most satisfactory amount of bitumen. The section was divided into four equal parts and the amounts of tar used originally were 1.77 gallons per square yard for the first, 2.18 gallons per square yard for the second, and

2.60 gallons per square yard for the third. When these three areas had been mixed and compacted they were given a prime application of 0.33 gallon of tar per square yard. Almost immediately, however, parts 2 and 3 shoved and rutted badly, apparently because of an excess of bitumen. Part 1 appeared lean but remained stable during a 2-week period under traffic. Parts 2 and 3 were remixed and relaid. The behavior of these 3 parts indicated that about 2.00 gallons per square yard should be nearly correct. Application of 2.08 gallons per square yard on the fourth part resulted in a mixture that was stable under traffic. Parts 2, 3, and 4 were primed with one-fourth gallon of 18 to 25 viscosity tar per square yard before the hot tar and stone cover were applied.

Within 2 months after construction sections A and B had become extremely rough and the excessive cracking which had developed gave them a very unsightly appearance. A hard, leathery crust formed on the surface, making it impossible to blade the surface to eliminate the roughness caused by shoving. After a considerable period of time the mixture apparently developed stability and internal movement decreased, but surface smoothness was never obtained to any high degree even after the sections were given a surface treatment and a stone cover in 1931.

Section C was considerably more satisfactory in behavior than sections A and B, but not nearly as satisfactory as sections D and E. The east end of section C required fairly heavy maintenance in its early life, partly because of subgrade failure and partly because of the unstable mat. This portion of the section contained a considerable amount of clay, both in the subgrade and in the mixed base.

Sections D and E were quite satisfactory from the start. Their bases were stable and their surfaces were smooth and generally free from cracking or raveling. Because of its high crown, section E required somewhat more maintenance than section D to remedy edge failure.

In 1931 the entire experimental section was given its first re-treatment which consisted of 0.36 gallon per square yard of the TC grade 5 tar having a specific viscosity of 48.7 at 40° C. and 37 pounds of ¾- to ¼-inch stone per square yard. This treatment considerably improved the condition of all of the sections but did not eliminate entirely the surface roughness of sections A, B, and part of C.

When inspected in March 1934 all of the sections were in need of a re-treatment. Sections A and B were both excessively rough, and on section B an appreciable portion of the base had been replaced by new mixed material to obtain stability.

EXPERIMENT 7 REMAINED IN GOOD CONDITION AND GAVE SATISFACTORY SERVICE

Sections C, D, and E had lost their uniform appearance due to whipping off of the cover stone, but with the exception of a portion of section C all were fairly smooth.

The construction and average annual maintenance costs for experiment 6 are given in table 12. The average annual maintenance costs as given might indicate equivalent behavior of section C as compared with sections D and E; however, at no time in its life was section C as satisfactory as the other two.

TABLE 12.—*Construction and average annual maintenance costs per square yard for experiment 6*

Section	Construction costs				Average annual maintenance costs
	Bituminous material	Cover material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	38.84		10.52	49.36	3.10
B	51.96		11.98	63.94	4.18
C	43.91	9.58	9.80	63.29	2.78
D	41.70	9.65	10.96	62.31	2.59
E	37.54	9.58	12.77	59.89	2.84

Experiment 7, extending from station 794 to station 1000, had a 2-inch mixed base of sand-clay and cutback asphalt. It was sealed with hot asphalt or cutback and covered with crushed stone.

This experiment covers three sections in which the base was a 2-inch mixture of 85 to 100 penetration cutback asphalt. The surface treatment was a hot asphalt on sections A and B, and an 85 to 100 penetration cut-back asphalt on section C. All three sections were covered with 1¼- to ¼-inch stone.

The surface and subgrade on this experimental section varied somewhat throughout its 4-mile length but appeared to be of sandier composition than most of the preceding sections. The sand-clay was broken up readily with the blade and the newly exposed, untreated base broke up under traffic and also under the construction equipment so that the resulting mixed base was actually as much as 6 inches thick in the sandiest locations. Mixing was easily accomplished and, when laid down, the mixture compacted readily into a smooth, well-bonded mat that did not dust under traffic. A light prime of 85 to 100 penetration cutback was applied to sections A and B but not to section C. Sections A and B then received the application of hot asphalt and stone cover, and section C received an application of the 85 to 100 penetration cutback and a stone cover.

The design of section A of experiment 7 was similar to that of section E of experiment 6 in that varying quantities of bitumen were used in the base. The amounts originally applied were insufficient for the east half and excessive on the west half. The section was remixed, adding bitumen to the east half and additional untreated material to the west half. When the mixing was completed the mat compacted and bonded readily under traffic and when surface treated it appeared to be in excellent condition.

Considerable roughness developed on a short curved area at the east end of section B and on two areas of section C. This was caused by a combination of bad subgrade conditions and lean base. These areas were scarified, remixed, and re-treated in 1929.

Except for the failure just mentioned, experiment 7 has remained in good condition and has given excellent service. Surface roughness caused by subgrade settlement gradually developed eventually but no inherent weaknesses, that could not be eliminated by surface treatment, made their appearance. Only one re-treatment has been given since construction, and that was applied to section A in 1932 and to sections B and C in 1931. It consisted of 0.42 gallon of 150 to 200 penetration cutback and 35 pounds of ¾- to ¼-inch stone per square yard for section A, and 0.32 gallon of 85 to 100 penetration cutback and 40 pounds of ¾- to ¼-inch stone per square yard for sections B and C.

The good behavior of this experimental section is reflected in its average annual maintenance cost and in its condition which, in March 1934, showed it to be stable and free from cracking, raveling, or other evidences of impending failure. Its surface roughness could be eliminated by a fairly heavy re-treatment.

The construction and average annual maintenance costs per square yard for experiment 7 are given in table 13.

TABLE 13.—*Construction and average annual maintenance costs per square yard for experiment 7*

Section	Construction cost				Average annual maintenance costs
	Bituminous material	Cover material	Labor, supplies, and equipment	Total	
	Cents	*Cents*	*Cents*	*Cents*	*Cents*
A	28.67	9.58	7.92	46.17	[illegible]
B	30.84	9.60	8.20	48.64	2.63
C	25.80	9.58	9.88	45.26	[illegible]

SURFACE ON EXPERIMENT 8 WAS VERY SATISFACTORY AND ECONOMICAL

Experiment 8, extending from station 1000 to station 1087, was a surface treatment of sand-clay with a prime of tar or cut-back asphalt. It was sealed with hot asphalt and covered with crushed stone.

This experiment was included in the project for comparison with the mixed-base experiments and also with similar treatments that were constructed elsewhere in the State upon other types of bases believed at that time more suitable for such treatment.

The sand-clay surface of this experimental section was, in general, more stable than that on the other sections due to a higher percentage of coarse sand. In this respect the west half of the section appeared to be more satisfactory than the east half.

The main difficulty experienced in constructing experiment 8 was in the preparation of the surface for treatment. The road was scarified and shaped with a blade grader to produce a uniform cross-section. Compaction was obtained by traffic and only under favorable moisture conditions. Three times, each just after a rain, the surface was lightly bladed while in a moist condition, removing the blade grader before the surface dried appreciably to prevent the accumulation of loose material that would not bond when dry.

After it had been consolidated as well as possible, the surface was swept with a rotary broom and by hand. After sweeping, it presented a very ragged appearance owing to the many depressions found where sand pockets had previously existed. These depressions were filled with stone before applying the prime.

Approximately 0.3 gallon per square yard of 8 to 13 viscosity tar was applied as a prime, but many small areas were not satisfactorily covered. A light second application of tar, however, successfully covered these areas and gave the surface a uniformly well-primed appearance. The total amount of tar prime used was 0.47 gallon per square yard. As the quantity of light tar on hand was insufficient for priming the entire section, a portion at the east end of the section, stations 1000 to 1026, was primed with 85 to 100 penetration cut-back asphalt at the rate of 0.55 gallon per square yard.

After an interval of 4 to 6 days during which traffic was excluded, the primed base was given an application of 0.38 gallon per square yard of 150 to 200 penetration asphalt applied at 275° to 315° F. and was immediately covered with 60 pounds per square yard of 1¼- to ¼-inch stone. Light rolling followed the spreading of the stone cover and in this operation considerable care was required to prevent breaking the mat.

Rather intensive maintenance was required for the first 2 months until the first re-treatment was applied in December 1927. In spite of this, however, the cost of experiment 8 for the first year, both for maintenance and for the seal, was less than the average for the remainder of the experimental sections. Since the December 1927 treatment, experiment 8 has received only one re-treatment. The portion between stations 1026 and 1087 was re-treated in 1929 and the remainder was re-treated in 1931.

During its life the principal defect of this section has been its surface roughness which, while considerable, was not as pronounced as that of some of the other sections. Roughness was caused by slight subgrade movement, not by failure of the surface mat. Some cracking has occurred more recently but the surface has not raveled or shoved.

Considering its construction and maintenance costs, this experiment has been surprisingly satisfactory and economical. The stability developed by the sand-clay mixture was greater than had been anticipated, and construction of the waterproof surface enable the base to retain this stability. The section weathered the winter of 1933–34, which was an unusually severe one, in excellent shape, in contrast to similar projects nearby. On these latter projects clay-gravel bases with high clay contents had been constructed on the loosely bonded sand-clay surface, and upon these bases surface treatments similar to those of experiment 8 had been constructed. The repeated cycles of freezing and thawing and the effect of moisture on the clay-gravel base resulted in extensive cracking and many areas of complete disintegration of these surfaces. Surface repairs proved inadequate for such failures and the only alternative was removal of the clay-gravel base, substitution of a pre-mixed, sand-asphalt base, and the construction of a new surface. No such repairs have been required on experiment 8. Figure 12, taken 4 years after construction, is typical of the appearance and condition it has retained since construction.

The cost per square yard of constructing experiment 8 were as follows:

	Cents
Bituminous materials	8.91
Cover material	9.58
Labor, supplies and equipment	6.50
Total	24.99
Average annual maintenance cost per square yard	3.54

RESULTS EMPHASIZED IMPORTANCE OF HAVING A STABLE SUBGRADE

Because of progress made in the field of low-cost bituminous construction since this experimental road was built, most of the details of construction and many of the facts established by this experiment are already well known and accepted. However, the great variety of factors covered by the experiment and the fact that it has been under close observation for 7 years justify some discussion of the observations made and the data accumulated during this period.

The discussion is based entirely upon conditions that obtained on this experimental road and consequently the conclusions drawn are not necessarily applicable to

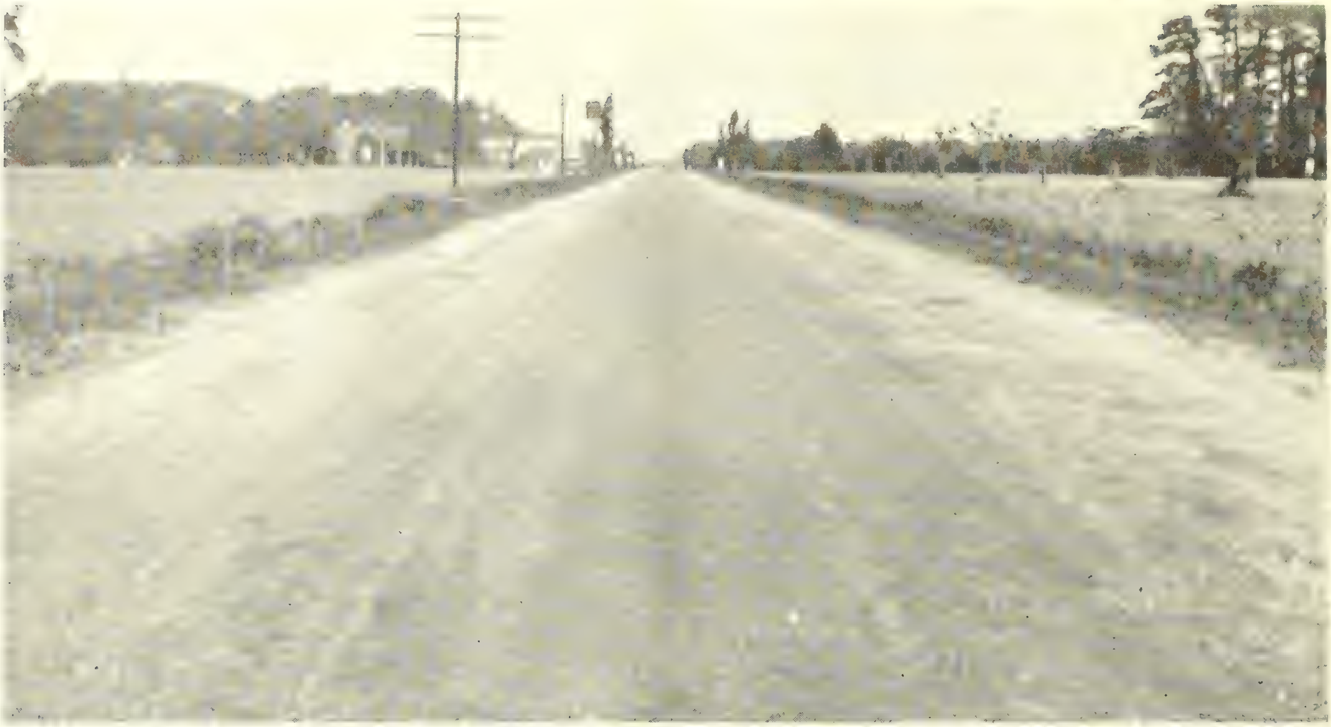

FIGURE 12.—VIEW OF EXPERIMENT 8 TAKEN 4 YEARS AFTER CONSTRUCTION. THIS IS TYPICAL OF THE APPEARANCE AND CONDITION IT HAS RETAINED SINCE CONSTRUCTION.

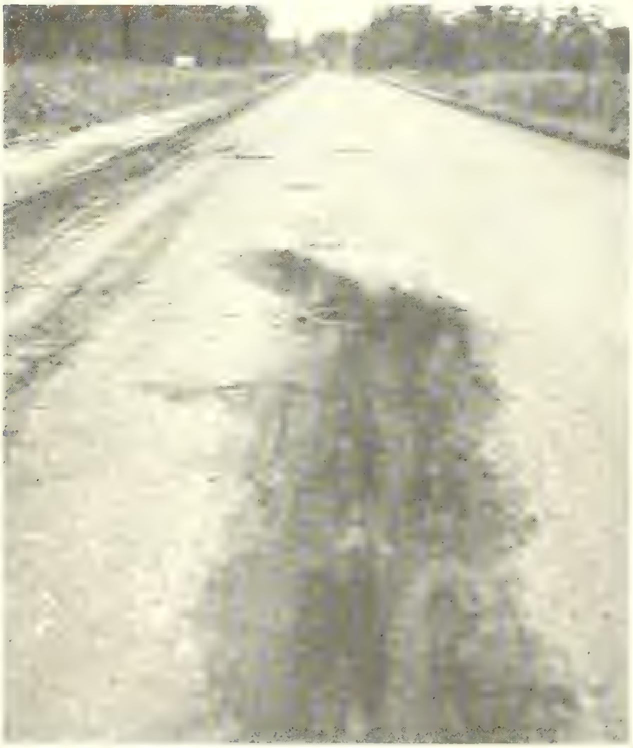

FIGURE 13.—POOR DRAINAGE RESULTED IN THE UNSATISFACTORY CONDITION OF THIS AREA OF EXPERIMENT 3 NEAR STATION 363. ANALYSES OF MAT AND SUBGRADE FROM THIS AREA ARE GIVEN IN TABLE 7.

other projects where the soils and drainage conditions are materially different. Table 4 shows that the soil on this road is a fine-grained, sandy material containing a large percentage of fine sand and small percentages of coarse sand, silt, and clay. It cannot be safely assumed that with other fine-grained soil materials as, for example, soils of high silt content but deficient in sand, the same results would be obtained in bituminous construction of the character described in this report.

The general belief that the service behavior of any flexible pavement is, to a great degree, dependent upon the character of its supporting subgrade is further confirmed by results obtained on this experimental road. The analyses given in table 7 show the subgrade to have properties characteristic of the A–2, A–3, A–4, and A–6 soil groups. Satisfactory and unsatisfactory surface conditions were found on both A–2 and A–6 subgrades and in most instances these conditions were associated with the drainage provided. An examination of the properties of experiment 3, given in table 7, illustrates quite clearly the effect of drainage. Only one area, that in the vicinity of station 365, continued unsatisfactory for much of the 7-year period, and this area, which was in a slight cut, was poorly drained. Its usual condition, illustrated in figure 13, is in marked contrast to the generally good condition of most of the experiment of which figures 14 and 15 are typical illustrations. Apparently neither the thickness of the bituminous mat nor its inherent stability offset the detrimental effect of poor drainage of its plastic subgrade.

Experiment 8, a thin, surface-treated section on a well-drained, plastic, A–2 soil, was considerably better than the poorly drained sections of experiments 3 and 4–B, although on the latter the bituminous mats were 2 inches and 3 inches thick originally.

The lack of uniformity in the character of the subgrade materials typified by the presence of A–6 soil immediately under the bituminous mat at stations 63 and 440, as well as in a more normally expected position at station 145 as shown in table 7, indicates in a measure the character of the maintenance presumably given the old road. Little information is available concerning previous maintenance. Apparently clay was used to stabilize the more sandy portions of the road and sandy materials were used on those areas where clay pre-

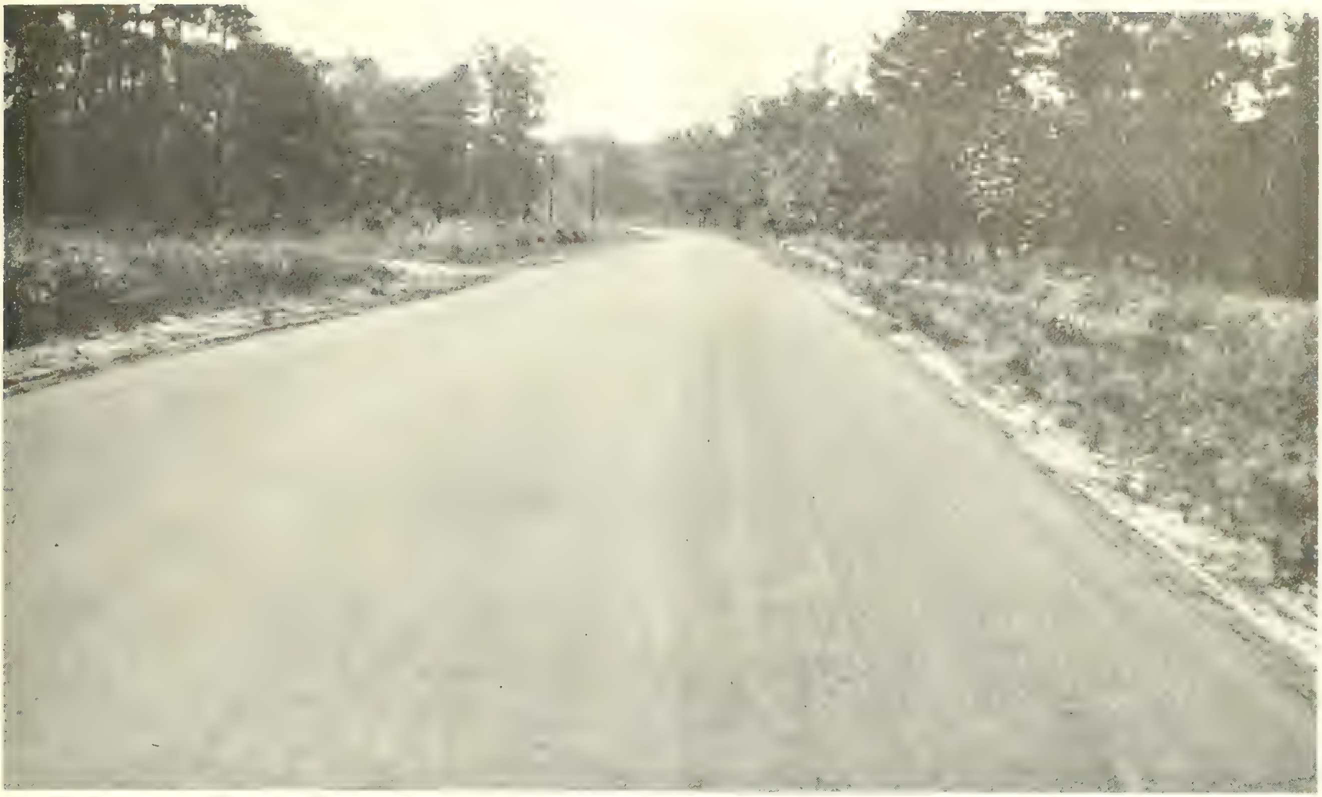

Figure 14.—General View of Experiment 3 at Station 353, Showing the Usual Condition of Most of This Experimental Section. Analyses of Bituminous Mat and of Subgrade Are Given in Table 7

dominated. Manipulation of the clay and sand to obtain a uniform surfacing material evidently had not been done.

Two comparisons for which information was desired were obscured by the effect of variations in subgrade. They were the effect of the consistency of the asphaltic cement used in the cut-back materials and the effect of the depth of the mixed bases and surfaces. Experiment 2 included sections in which the only variable in construction methods and materials was the penetration of the asphalt used in the cutback, but at no time during the period covered by this study did this difference in penetration have any apparent effect on the sections. Experiment 5 was designed to study the relative merits of 2- and 3-inch bases but here, too, the subgrade effectively prevented a true comparison.

On the other hand, the condition of the subgrade did provide one opportunity for a comparison that would not have been possible had it been either uniformly good or bad. This was a comparison of the service behavior of the slow-curing oils used in experiments 3 and 4. The construction and maintenance of these two experimental sections have been approximately the same, the only differences being the oils used and the fact that the mat on experiment 3 was 2 inches thick while that on experiment 4 was 3 inches. This fact, however, is believed to have had little bearing upon the performance of these sections. It seemed apparent that the difference in service behavior of the two sections was primarily caused by the characteristics of the oils.

MIXTURE RETAINED HALF OF ITS ORIGINAL VOLATILE MATTER 7 YEARS AFTER CONSTRUCTION

The three types of bituminous materials used in the mixed bases were cold-application materials of relatively low viscosity. The slow-curing oils were not expected to harden greatly or increase in cementitiousness in service. The cut-back asphalts and the 18 to 25 viscosity tar, however, contained volatile material which was expected to be lost during construction or shortly thereafter, leaving a bituminous residue of a consistency sufficiently high for good binding quality. During construction no difficulty was encountered in manipulating and spreading the mixtures or in remixing some of the cut-back sections after a year or two. Neither the tar nor the cutbacks stiffened appreciably except on the immediate surface until considerable time had elapsed. The actual loss of volatile matter during construction was not determined but was apparently much less than had been expected.

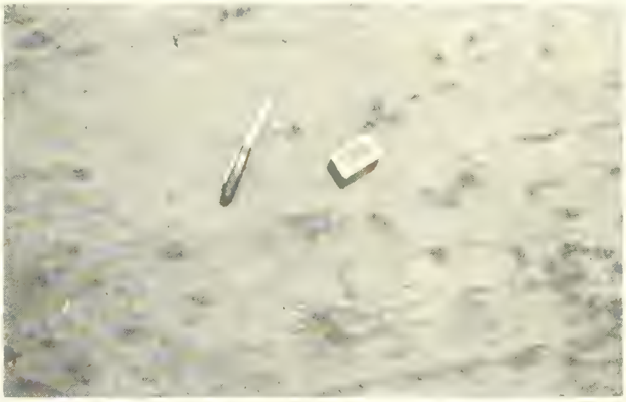

Figure 15.—Illustration of the Closed Texture Characteristic of Most of Experiment 3. Analyses of Mat and of Underlying Subgrade at Station 353 Are Given in Table 7.

A sample, whose analysis is given in table 7 under laboratory no. 39362, representing the full depth of the original mixed base containing cut-back asphalt, was taken 7 years after construction to determine whether it still retained any appreciable amount of volatile matter. Upon examination it showed that 18.4 percent of the existing bitumen was volatile matter as determined by an oven test made on the mixture at 325° F. Since the cutback used originally showed a maximum loss of 33.9 percent at 325° F. in the standard oven test, it is indicated that approximately 53 percent of the volatile matter was still present after a period of 7 years. It seems apparent, therefore, that the loss of volatile matter at the surface resulted in the development of a viscous material which, in combination with the fine-grained aggregate, formed a tight seal that effectively prevented the escape of the volatile matter in the binder below the surface. Evidently the rate of hardening of the cut-back asphalt was more dependent upon the manner in which it was used than upon the character of its volatile constituent.

For the conditions existing on this road it is apparent that manipulation of the mixture could well have been continued over a longer period of time. Had this been done, a higher consistency would have been developed by the bituminous material with a corresponding lessening of the effect of the variation in the grading of the mineral aggregate. Later practice has been either to continue manipulation to eliminate as much of the volatile material as possible without leaving the mixture too tacky to spread and compact, or to apply the bitumen in smaller increments and to do considerable manipulation after each application. The latter method is probably better as it would afford the engineer a better opportunity of making a final decision as to the correctness of the mixture.

The penetration of the asphalts used in the cut-backs ranged from 85 to 180. The effect of this difference in penetration was not apparent either on the relative durability of the material or upon the re-treatments required. In all cases other factors so overshadowed the difference in the cut-back asphalts that their comparative values could not be established.

The slow-curing oils differed considerably from the cut-backs in their characteristics and behavior as a binding medium. As shown by the analyses, given in table 1, they contained relatively small amounts of volatile matter as determined by the standard oven test and the residues from this test were fluid. The behavior of experiment 3 was considerably different than that of experiment 4 due to the characteristics of the oils used. The mixture of experiment 3 did not develop the brittleness and raveling typical of experiment 4. Analyses of the oils used in the two experimental sections likewise showed a considerable difference in characteristics. Oil A, which was furnished as a straight reduced material, had a low specific gravity and high solubility in naphtha. Oils B, C, and D had relatively high gravities and low solubilities in naphtha, indicating that they were more highly cracked in the process of manufacture than was oil A, or that they contained greater percentages of cracked material.

TAR MIXTURES ATTAINED GREATER STABILITY THROUGHOUT DEPTH THAN DID CUT-BACK MIXTURES

In the re-treatment of experiments 3 and 4 in 1928 and 1933 it was intended to use the same type of oil that was used in the construction of experiment 3, but analysis of the oil used showed it to have characteristics more nearly like those of oils B, C, and D, indicating that it, too, was a cracked oil. Analyses of the oils used in the re-treatment of sections B and C of experiment 4 in 1930 are not available but were supposed to be the same as those of the oils used in their original construction. Considering the characteristics of the oils used in the re-treatments of 1928 and 1933, it is most likely that the oils used in 1930 were not greatly different from those used originally. The difference, if any, was at no time apparent in the behavior of sections A, B, and C.

Except for crusting of the immediate surface, experiment 3 continued more malleable throughout its life than did experiment 4. The stabilities developed by the mixtures in their early life were comparatively low and while they increased slowly, that of the mixture of experiment 4 increased more rapidly than that of experiment 3. The surface of both experimental sections was abraded somewhat by traffic and the loosened material dissipated, but experiment 3, because of its higher plasticity, in general, suffered less from mutilative traffic and, when disturbed, rebonded much better than did experiment 4. The latter experimental section, however, appeared to be less affected by moisture.

On sections A and D of experiment 5, oil E, which was similar in character to oil B, was used for the surface enrichment of the mixed base in which a cut-back asphalt had been used. In this case the mixed base developed a certain degree of hardness while the upper portion, enriched with the slow-curing oil, remained more plastic. This resulted in considerable shoving and displacement of the surface which soon became so rough that re-treatment with cut-back asphalt and stone cover was necessary to restore a satisfactory degree of smoothness. Figure 7–A illustrates the rough condition of section 5–D caused by surface enrichment with slow-curing oil.

On experiment 8 a tar of 8 to 13 specific viscosity and a naphtha cut-back asphalt were used for priming the sand-clay base prior to surface treatment. Rapid-curing material such as cut-back asphalt is seldom used for priming purposes and it was used here only because of a shortage of tar prime. Little difference in behavior of the areas thus primed has been apparent so far. The area on which the cut-back was used however, was sandier and more open than the remainder of the section, which probably accounts for the penetration of the cutback.

The 18 to 25 viscosity tar used in the mixed base of experiment 6 and in the surface enrichment of sections A and B of that experimental section was comparable in some respects to the cut-back asphalts. It was a low viscosity, cold-application material containing a considerable amount of volatile matter and, upon losing this volatile matter, it developed a residue comparable with those of the cut-back asphalts in consistency. This change in consistency, while somewhat slow, extended through the full depth of the base and was not confined to the surface alone as in the case of the cut-backs. As shown in table 7, stability tests made on samples taken 7 years after construction show that the stability of the mixture 1 and 2 inches below the surface is relatively high in comparison with the top 1-inch of the tar mixtures, but in the cut-back asphalt mixtures the corresponding stability is substantially less for portions of the mixture below the surface than at the top.

Where the 18 to 25 viscosity tar was used in the surface enrichment of sections 6–A and 6–B it readily lost sufficient of its volatile matter to produce a hard crust which, however, was relatively thin. This same bituminous material within the mixture did not lose its volatile constituents so rapidly and as a result the base remained relatively plastic. As a consequence, considerable shoving and corrugating of the mat and cracking of the surface crust occurred. This condition continued in gradually decreasing intensity for approximately 4 years or, apparently, until the bitumen in the base had developed a consistency sufficiently high to provide the stability required. When stability had been developed as indicated by a cessation of mat movement, the sections were given the long-needed surface treatment which had been delayed for fear of retarding the slowly increasing stability.

BOTH HOT- AND COLD-APPLICATION MATERIALS USED TO SURFACE-TREAT MIXED BASES

The 25 to 35 viscosity tar and the hot tar were used as binders in the surface treatment of sections 6–C, D, and E to provide information on the relative merits of cold- and hot-application materials. At the time the 25 to 35 viscosity grade was thought to approach the maximum viscosity for cold application and though it may be considered to have been reasonably satisfactory, later experience has shown that considerably higher viscosity materials can be used advantageously. It will be recalled that in the re-treatment given experiment 6 in 1931 a tar of 48.7 viscosity at 40° C. was used. No difficulty was encountered in applying this material or in road-mixing it with the cover stone. In spite of the relatively high viscosity of the tar, approximately 10 days elapsed before the surface had stiffened sufficiently to resist picking up under traffic. This was believed due to the low rate of loss of volatile matter.

Analysis of the 25 to 35 viscosity tar is not available but it may be reasonably assumed that, like the 18 to 25 and the 48.7 viscosity tars used in the base construction and in the re-treatment of 1931, it contained some volatile matter which when lost would leave a base material sufficiently viscous to hold the cover stone. The hot material, on the other hand, would be expected to lose very little through volatilization, the fluidity desired for application purposes being obtained by heating. This basic difference between the hot- and cold-application binders was reflected in their behavior.

In surface treatment of the mixed bases both hot- and cold-application tars and asphalts were used with mineral covers. The hot-application materials, because of their high viscosity, did not penetrate into the mixed bases but remained on the surface, adequately holding the cover material to form a hard mat which received the wear of traffic.

The cold-application materials, on the other hand, penetrated into the base in varying amounts depending upon their viscosity and the denseness of the base. Penetration in any considerable amount resulted in softening of the mixed base with consequent reduction in its stability. Penetration also permitted the cover material to become embedded in the base, forming a mastic which received the wear of traffic. When less penetration occurred, softening of the base was not so pronounced, but the loss of bitumen by penetration as well as by evaporation reduced the amount available for holding the cover materials, which were thereby subject to displacement under traffic.

Where the mixed mat was well compacted before the surface treatment was applied, the cold-application materials did not penetrate and were satisfactory. An illustration of this is experiment 2–A, which has a record of excellent service behavior at relatively low cost.

In addition to the possibility of loss by penetration, evaporation losses also reduced the net amount of bitumen correspondingly. Increasing the amount of bitumen and modifying the method of applying the treatment might have offset these losses and also might have prevented penetration in some instances. It appears advisable and more practical, however, that the surface treatment material used should be of such viscosity that it will not penetrate into the base or else that the method of applying the treatment be such that penetration is reduced to a minimum.

The amount of bitumen used in the mixes of the different sections varied considerably, as shown in table 5. Some of this variation was planned, as in the case of experiments 6–E and 7–A, but in all other sections it was the result of the method of construction.

Formulas for determining the amount of bitumen to use with aggregates of a given grading have been developed more recently and used satisfactorily by a number of States. Such formulas apparently have very narrow limits of application since none is used widely outside of the State in which it was developed, and in most cases where used by other States some modification of the formula has been found necessary. In addition, the formulas are applied to aggregates whose grading is uniform and, regardless of the correctness of the formula, uniform mixtures should be expected.

IMPOSSIBLE TO DESIGN MIXTURES BY EMPIRICAL FORMULAS

With the exception of experiments 3, 4, 5, 6–A, and 6–B, the mixed sections served as bases, surface-treated with bitumen and mineral cover; consequently, they were designed for stability primarily and as a result contain less bitumen than they would have if they had been intended to serve as wear-resisting surfaces. Comparison of their bitumen content with any empirical formula would therefore serve no useful purpose. The mixed sections designed to carry traffic without any additional wearing surface do offer an opportunity for comparison of the percentage of bitumen actually used with that required by theoretical formulas and curves, although the variation in grading of the aggregate and the frequency with which this variation occurred would have made the application of an empirical formula futile in design.

On this project, experiments 3 and 4 were of uniform composition throughout their depth, while experiments 5, 6–A, and 6–B were leaner in the lower portion and enriched in the upper portion but were not covered with wear-resisting mineral cover. To present such comparison as can be made, the analyses of samples taken from the non-surface-treated sections are retabulated in table 14 for convenience. The data given in this table indicate that neither an empirical formula nor a numerical stability value, which is a variable characteristic, should be arbitrarily selected because of its successful use under other conditions or with bituminous materials of different characteristics. Table 14 shows that considerable variation in stability is found when different bituminous materials are used and also that numerical stability value alone does not indicate probable service behavior.

TABLE 11.—*Comparison of the kind and quantity of bitumen with stability of bituminous mixtures*

Sample no.	[illegible]	Type of bituminous material	Hubbard-Field stability at 77° F.			Amount of bitumen [1]		
			Maximum	Minimum	Average	Extracted from field samples	Required by—		Remarks
							Surface-area method	Nebraska formula	
			Pounds	*Pounds*	*Pounds*	*Percent*	*Percent*	*Percent*	
[illegible]	[illegible]	Slow-curing oil	1,620	1,550	1,585	7.64	[illegible]	5.34	Good area, stable when sampled; remains so in cool weather. Ruts slightly in warm weather but irons out under traffic. Stability appears adequate
39358	3	do	[illegible]	[illegible]	1,730	[illegible]	7.52	5.58	Poorly drained area in bad condition. Behavior in dry weather same as above.
39357	[illegible]	do	2,910	[illegible]	1,870	10.14	7.30	5.51	From a cracked area affected by moisture. Service behavior good. Stability appeared adequate when sampled.
39356a	4-B	do	[illegible]	[illegible]	[illegible]	10.14	7.17	[illegible]	New mixture on old mat, has no resistance to displacement except in cool weather. Stability when sampled was inadequate.
[illegible]	4-B	do	3,050	[illegible]	[illegible]	10.25	7.57	5.67	Old mat below sample above. Stable except in very hot weather. Dusts under traffic. Stability (against shoving) adequate when sampled.
[illegible]	4-C	do	[illegible]	700	[illegible]	[illegible]	[illegible]	[illegible]	Service behavior same as above. Stability when sampled was adequate.
[illegible]	4-C	do	1,160	[illegible]	1,045	[illegible]	7.10	5.52	Same as above
[illegible]	5-C	Cut-back asphalt	[illegible]	2,940	[illegible]	[illegible]	[illegible]	6.54	Retains stability irrespective of temperature. Continues in excellent condition except for edge failure. Stability adequate when sampled.
[illegible]	6-A	18-25 viscosity tar	[illegible]	[illegible]	[illegible]	7.53	7.60	[illegible]	Stability accompanied by dusting, increased with age. Surface rough, resulting from early movement. Stability adequate when sampled.
39360	6-B	do	5,710	[illegible]	[illegible]	[illegible]	[illegible]	5.12	Behavior and condition same as above.

[1] In terms of dry aggregate.
$P = 0.02a + 0.045b + 0.06c + 0.12d$ where
P = percentage of bitumen.
a = percentage of aggregate retained on No. 50 sieve.
b = percent passing No. 50 and retained on No. 100 sieve.
c = percent passing No. 100 and retained on No. 200 sieve
d = percent passing No. 200 sieve.
[3] Also see table 7.

It is apparent therefore that experience, excellent judgment, and great care on the part of the engineer are of utmost importance in the construction of road-mixed surfaces under conditions characteristic of this road.

For fine-grained, poorly graded aggregates such as were found on this road, the range in bitumen content between mixtures sufficiently rich to resist abrasion without shoving and those whose richness results in shoving is very narrow. Because of this it was practically impossible to obtain a satisfactory, stable, wear-resisting mat without surface treatment. This was tried on experiments 3, 4, 5, 6–A, and 6–B and was only partially successful.

On experiment 3, when the mat was rich enough to resist abrasion it displaced under traffic, especially in warm weather. However, it retained its malleability, and such surface irregularities as occurred were readily ironed out by traffic. As the viscosity of the oil increased because of lower air temperatures or by oxidation caused by weathering, the resistance of the mat to slight movements increased and was usually accompanied by dusting. Addition of the same type of oil eliminated dusting, but, at the same time, reduced the ability of the mat to resist movement.

The behavior of experiment 4 was similar to that of experiment 3, although here greater stability as well as increased dusting and raveling were characteristic. The two sections of experiment 5, on which the slow-curing oil was used, were unsatisfactory without surface treatment because of their inability to resist displacement. The other two sections of experiment 5, on which a rapid-curing material was used in surface enrichment, continued the most stable of the sections not surface-treated. The mats were firm and hard, and did not dust appreciably under traffic. They were rather rough, however, and their edges suffered from mutilative traffic. Sections 6–A and 6–B, which were surface enriched but not surface treated, were unsatisfactory also. The amount of bitumen required to prevent dusting produced a mixture that shoved considerably and was excessively rough.

Comparison between the surface-treated bases in general with the sections not so treated demonstrates the advisability of constructing a rather lean mat of adequate stability and upon it constructing a wear-resisting surface. This method of improving the loosely bound, sand-clay roads such as were found on this road has been used by the State with considerable success on a rather extensive mileage.

MIXING OF RE-TREATMENTS GAVE BEST RESULTS

With the exception of six sections of experiment 2, all sections that were surface-treated were covered with crushed granite 1¼ to ¼ inch in size. The exceptions were sections 2–B, 2–E, and 2–H on which pea gravel was used, and 2–C, 2–D, and 2–I on which local pit-run sand was the cover material.

One of the pea-gravel sections was resurfaced with stone in its earlier life but the necessity for re-treating was not caused by any failure of the original cover material, and stone was used in the re-treatment merely as a matter of convenience. Although the gravel cover did crush somewhat under the roller and under traffic no failures directly attributable to its use were apparent.

The sand-covered sections were re-treated early in their life and, while subgrade conditions and unstable mixed bases were the main causes for reconstruction and re-treatment, the use of sand as a cover also contributed greatly to the failure of these sections. The same low-viscosity, cold-application material used in the mixtures was used as a seal in combination with the sand in surface treatment, with the result that the sand

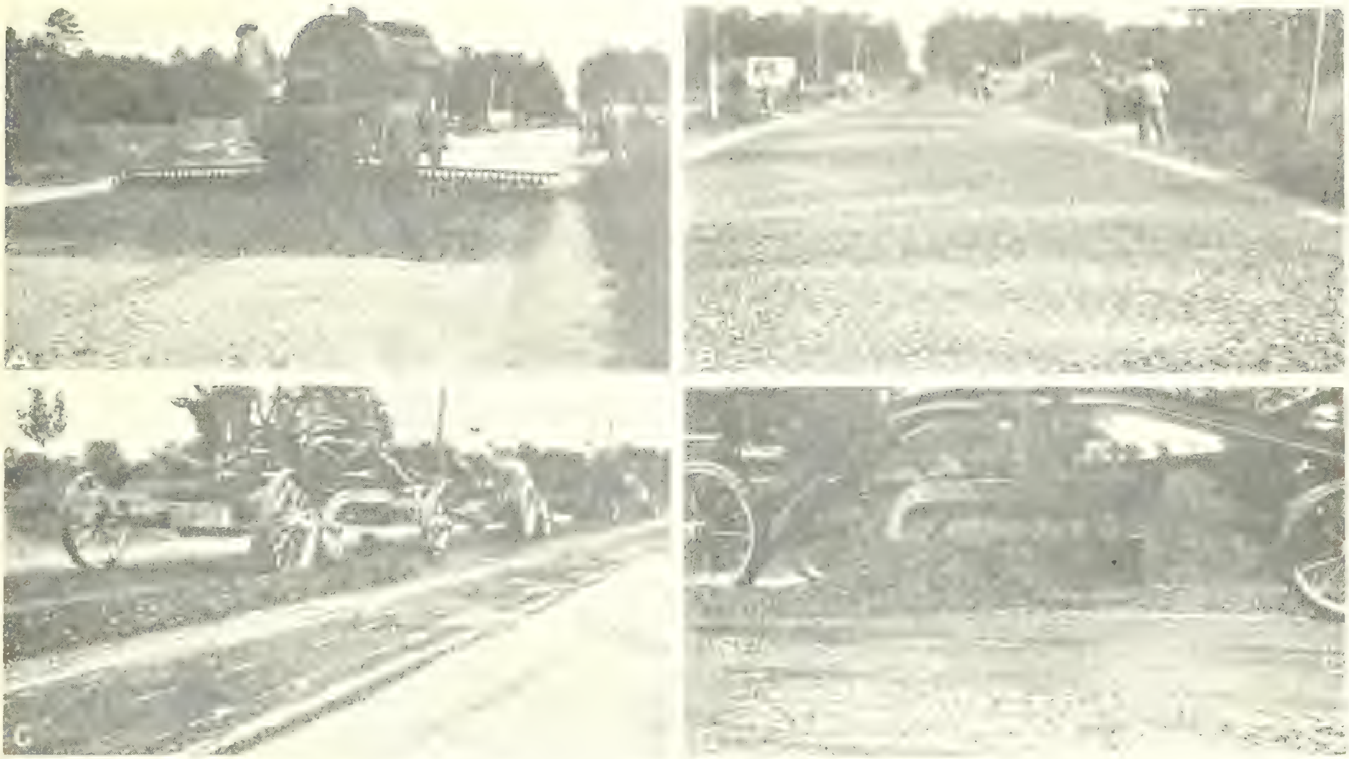

Figure 16.—Steps in the Application and Mixing of a Re-treatment. A, Applying Bitumen. End Nozzles Were Turned 90° to Obtain Heavier Application at the Edges. Note that Some Cover Material Has Been Spread Prior to Applying Bitumen. B, Spreading Cover Material Immediately After Applying the Bitumen. C, Manipulating Cover Material and Bitumen in Mixing the Re-treatment. D, Mixing the Re-treatment. Variable Appearance Results from Surface Irregularities. Blade Picks Up Cover Material from High Spots but Cannot Remove It from Depressions, so this Work Is Done by Hand.

became a part of the mixed base instead of serving as a protection against traffic wear. Three types of failure developed in these sections; pot-holing, edge failure by abrasion under traffic, and excessive roughness caused by loss of stability in the mixture due to the increase of bitumen.

Section 2–I was covered with stone 1 year after construction and sections 2–C and 2–D were similarly treated a year later. This treatment eliminated the failure not caused by subgrade conditions.

In the re-treatments following construction, crushed granite, usually three-fourths to one-fourth inch in size, was used except on section 2–B on which the gravel cover has been retained.

In applying re-treatments to the various sections, effort was made to continue the type of experiment unchanged as long as possible, or until it was demonstrated that no useful purpose would be served by continuing it unchanged and that better service could be obtained by changing it. In the early life of the experimental sections the re-treatments consisted of applying the same type of bituminous material and of cover that were used in the original construction. The inability to differentiate between the merits of the various grades of cut-back and the unsatisfactory results obtained from using sand as a cover soon resulted in the adoption of a single grade of cut-back and the use of stone only as cover material except in the case of section 2–B.

The majority of re-treatments were applied to eliminate surface roughness caused primarily by base and subgrade settlement and by movement of the richer mixes, especially during their early life. In applying re-treatments the cover materials were spread by hand and, in the earlier treatments, they were broomed by hand and by dragging to obtain a smooth surface. Later, however, as subgrade settlement increased with a correspondingly greater surface roughness, the plan of mixing and spreading the bitumen and cover used in re-treatment with blades or drags was introduced. This method, which was an innovation at least in this part of the country, was very satisfactory and the resulting surfaces were smooth, but obviously not uniform in depth. Where the existing mat was remixed prior to applying the surface re-treatment, mixing of the bitumen and aggregate composing the treatment was not done. Where the existing surface was not to be disturbed the blade-mix method was always used.

Some advantages of using the blade-mix method, which are not obtained without using it, are the elimination of pools of bitumen in low spots, a more uniform mixture, little or no loss of cover stone, and a uniform-appearing surface on which traffic will travel over the full width. Where mixing is not done, considerable cover stone is lost by traffic even though the surface has been rolled, and traffic tends to travel in a single lane. Figure 16 illustrates the method of applying the later re-treatments to the sections of this road. This method is used almost entirely by the State at the present time. The surface appearances of mixed and unmixed re-treatments are shown in figures 17 and 18

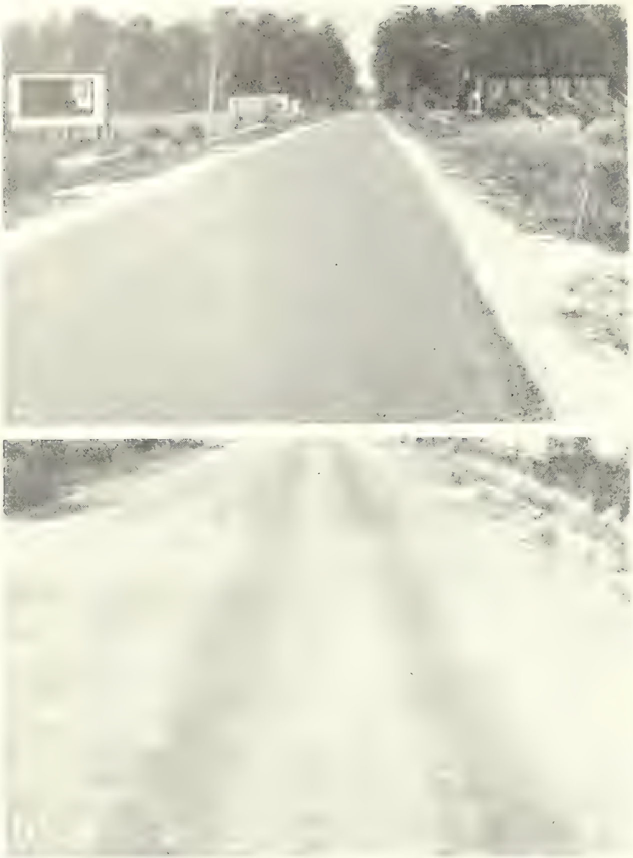

Figure 17.—A, Typically Uniform Appearance of a Mixed Surface Re-treatment. B, Appearance of a Newly Re-treated Surface That Was Not Mixed. On Such Surfaces Traffic Has a Decided Tendency to Travel in a Single Lane.

TYPE OF EXPERIMENT HAD NO DIRECT RELATIONSHIP TO MAINTENANCE COST

Maintenance of the roadway proper consisted of such patching and replacements as were necessary and the application of re-treatments to the old or reconstructed base and surface. This work is included in the maintenance costs given herein which do not, however, include such work as the construction and maintenance of shoulders, side ditches, or the installation of supplementary drainage fixtures.

With the exception of experiments 3 and 4, the experiments were not designed for machine maintenance, and repairs were made by patching and by re-treatment. Experiments 3 and 4 were included to provide a comparison not only of the oils used but also of methods of maintenance. The mats of these two experimental sections remained relatively malleable in comparison with those in which cut-back asphalts and tars were used, but because of surface crusting caused by hardening of the bitumen at the surface they were not suited to machine maintenance, contrary to expectations. Under favorable conditions the surface could be lightly cut for smoothing purposes, though the material thus cut from high spots did not bond in the depressed areas but was whipped from the surface by traffic. Continual blading to maintain smoothness on such surfaces could only result in the dissipation of the entire mat. The alternative to excessive planing was remixing of the entire mat with or without the addition of bitumen.

Since the period covered by the cooperative study of this experimental road, considerable success has been attained in lessening the effect of certain unfavorable subgrade conditions by building a new sand-cutback-asphalt mat over the old surface. The depth of the new mat is varied from 3 to 8 inches depending upon the condition of the subgrade and old surface.

Costs of the experimental sections, both for construction and for maintenance, are given in table 6. In considering these costs it should be remembered that the old road had been maintained as a sand-clay project whose behavior has already been described and also that supplementary drainage had not been provided, nor had any grade lines been established. Work of this character which has been done since construction, such as installing French drains and pipe, and banking curves, has necessitated additional patching and the use of extra surfacing materials, and as a result has had some effect on the cost of maintenance. The shortness of the sections and the variety of materials used both in construction and early maintenance also added to the costs.

It might be expected that the maintenance cost would be about inversely proportional to the construction cost. Such, however, was not the case nor did the type of experiment bear any direct relationship to the maintenance cost. Experiments 1–B, 7–A, and 7–B were identical in construction, differences in cost being due primarily to length of haul. The maintenance cost of experiment 1–B, however, is 2.7 and 3.3 times that of 7–A and 7–B, respectively, and its total cost for the period is more than 50 percent greater than these two in spite of the fact that they cost approximately 50 percent more to construct. This difference in maintenance cost can be attributed almost entirely to the additional maintenance required on experiment 1–B because of subgrade failure. The low maintenance cost of experiment 6 cannot be assumed to indicate continued satisfactory service for, as stated previously, the instability of the mixture on this experiment made it inadvisable to apply surface treatments which should have been applied to eliminate the surface roughness that was characteristic of the experiment throughout most of the period.

CONSTRUCTION AND RE-TREATMENT OPERATIONS DID NOT INTERFERE WITH TRAFFIC

Sections A, F, and G of experiment 2 were identical except for the consistency of the base asphalt used in the cut-back. Sections B, E, and H, and C, D, and I were alike in the same way. The difference in maintenance cost between A, F, and G, represents approximately the differences in subgrade conditions, and the same applies also to sections B, E, and H. Sections D, E, and F were the same except for the cover materials which were sand, gravel, and stone, respectively. Subgrade conditions appeared about the same on sections D and E and were better than on F, and the differences in cost fairly well reflect the differences in amount of surface maintenance required.

Experiment 8, the double surface-treatment constructed on sand-clay, was maintained at a relatively low cost in spite of its low construction cost. The subgrade soil on this experiment, contrary to early expectations, proved quite satisfactory for the type of construction used because the drainage was apparently adequate.

Another item entering into the cost of maintenance but not indicated by the figures alone was the additional work done in superelevating some of the curves, nor is the actual condition of the sections from day to day indicated by a study of the cost figures. Some sections were decidedly smoother than others, some were rather rough most of the time, and some, such as experiments 3 and 4, continued in a loose condition for some time after re-treatment and, even after they had become compacted, became soft during hot weather. All such points must receive consideration in any attempt to evaluate the different sections from the standpoint of cost and adequacy.

The experimental road, at the time of its completion, did not connect with or touch any part of an improved highway system with all-weather surfaces. The traffic carried by the road prior to construction was mostly local, a fair proportion of which was horse-drawn vehicles carrying from light to relatively heavy loads. Some motor vehicles used the road, but few trucks or busses. The last traffic count, taken before the experimental sections were constructed, showed the road to be carrying 486 vehicles daily. One year after construction it was carrying an average of 559 vehicles daily.

With the gradual improvement of highways in this area other satisfactory travel routes became available for both local and through traffic. Despite this fact, however, the 1935 count shows a considerable increase in traffic since construction of the project. In addition it shows the relatively heavy traffic carried during the summer months when the stability of the various sections is presumably the lowest. Differentiation is also made between the traffic carried by the eastern and western portions of the road. The eastern portion extends from Homewood to Conway, is a part of both United States Highways Nos. 501 and 701, and embraces experiment 1 and about half of 2–A. The western portion of the road extends from Homewood to Gallivants Ferry, and is a part of United States Highway No. 501 only. The average daily traffic recorded for 1935 is shown in table 15.

Table 15.—*Daily average traffic carried by the experimental road*

Portion represented	Daily average traffic for 1935	Daily average traffic for June, July, and August 1935	Daily average traffic, remainder of 1935
	Number	*Number*	*Number*
Conway Homewood	977	1,087	942
Homewood-Gallivants Ferry	558	701	511

The fact that the road surface is still in service and is in better condition generally than at any previous time has demonstrated the practicability of correcting, by subsequent maintenance and retreatment, many errors made initially in the choice of materials or in the methods employed. In effect, the road has been built by stage construction, with the maintenance and each re-treatment adding something to the permanent improvement of the road structure. For this reason, therefore, an appreciable part of the accumulated maintenance cost might be more properly charged on the side of construction.

Another feature merits special attention. During the construction period and also while the re-treatments were being applied, traffic was never seriously interfered with and was only slightly inconvenienced at the most. This fact is of no small importance when the matter of detours is considered, especially in localities where the topography is such that detours not only are expensive to provide and to maintain but may become traffic hazards of decided proportions. So far as the experimental project is concerned, passing traffic not only was not detrimental, but during construction served the very useful purpose of providing compaction for the mixed mats and in so doing made it possible more accurately to determine the correctness of their proportions.

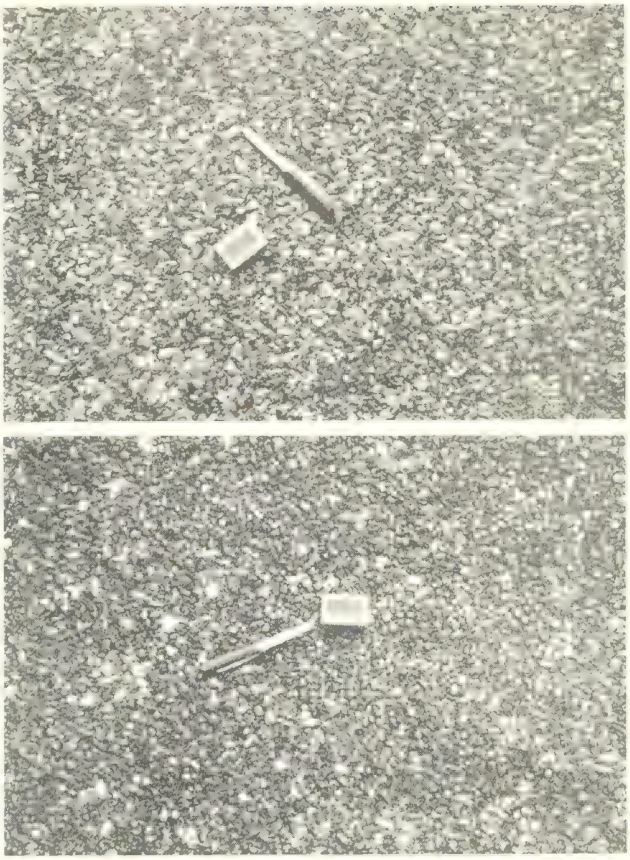

Figure 18.—Appearances of Surfaces of Mixed Re-treatments. A, Aggregate is ¾- to ¼-inch Stone. B, Aggregate is Pea Gravel.

CONCLUSIONS

The facts that appear to have been established during the period covered by this report may be summarized as follows:

1. The serviceability of the experimental surfaces which comprised this project was more greatly affected by the character of the subgrade than by the type of bituminous surface.

2. Failures caused by unsatisfactory subgrade conditions were not eliminated by repairs to the bituminous bases and surfaces but by the removal of the unsatisfactory subgrade materials or by providing adequate drainage.

3. Provision of a substantial subbase prior to construction of the bituminous mat will reduce considerably the cost of maintenance, which is a continuous cost.

4. The surface portions of loosely bonded sandy soils containing little or no clay were treated with a bituminous binding material to form bases satisfactory for thin bituminous wearing surfaces.

5. For loosely bonded, poorly graded, fine-grained aggregates the bituminous material must provide the stability lacking in the aggregate.

6. Manipulation of mixtures containing low-viscosity, cut-back materials should be continued until a considerable portion of the volatile matter has been dissipated.

7. The consistency of the bituminous material used in surface treatment exclusive of the priming application should be such that it will not penetrate into the base, or the method of applying the treatment should be such that penetration is reduced to a minimum.

8. Slow-curing oils that retained their fluidity for a considerable period of time did not compensate for a lack of mechanical stability in the fine aggregate but did produce mixtures that remained plastic under traffic and that, when remixed, readily rebonded with or without additional oil.

9. Slow-curing oils whose fluidity decreased because of weathering developed some binding property but produced mixtures that became brittle and subject to dusting under traffic, and did not rebond without additional oil.

10. With fine-grained, poorly-graded aggregate it was difficult to obtain a bituminous mixture that was sufficiently stable and at the same time would withstand abrasion under traffic.

11. Mixtures of the type used on this road that were sufficiently stable to resist shoving proved more satisfactory when protected with a wear-resisting surface than those that were sufficiently rich to resist traffic abrasion without a protective covering.

12. In re-treatment, a higher degree of smoothness was obtained by machine mixing and spreading the bitumen and aggregate than by hand spreading and brooming alone.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF DECEMBER 31, 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 5,208,287	$ 51,600	$ 25,800	9.0	$ 697,081	$ 348,540	20.1	$ 730,700	$ 365,350	35.3	$ 4,468,597
Arizona	3,564,709	1,845,199	1,436,431	102.5	1,045,703	812,377	37.8	276,405	[illegible]	[illegible]	1,121,542
Arkansas	4,275,929				470,883	470,465	11.8	1,951,877	1,950,625	98.3	1,854,839
California	9,508,671	5,083,641	2,926,297	138.8	[illegible]	[illegible]	[illegible]	[illegible]	912,617	[illegible]	[illegible]
Colorado	4,575,144	3,314,313	1,757,167	125.1	2,977,467	1,674,259	108.0	1,224,0[illegible]	[illegible]	[illegible]	477,715
Connecticut	1,582,913	501,875	250,937	9.5	705,601	[illegible]	[illegible]	[illegible]	141,550	4.0	[illegible]
Delaware	1,218,750	305,920	152,960	30.3	414,548	201,754	11.8	[illegible]	161,257	13.4	[illegible]
Florida	3,315,558	826,514	407,278	27.5	[illegible]	[illegible]	[illegible]	1,476,200	738,100	42.6	[illegible]
Georgia	6,336,443	938,571	433,[illegible]	72.1	2,709,3[illegible]	[illegible]	[illegible]	[illegible]	321,[illegible]	31.2	[illegible]
[illegible]	3,0[illegible],304	2,473,020	[illegible]	[illegible]	[illegible]	[illegible],712	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	10,325,922	[illegible],740	3,334,610	164.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible],134,258	5,149,[illegible]	[illegible]	167.8	[illegible]	1,302,43[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible],317,100	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,001,78[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Maryland	2,050,870				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Massachusetts	3,435,764	333,935	[illegible]	3.1	[illegible]	[illegible]	26.3	[illegible]	[illegible]	[illegible]	[illegible]
Michigan	7,668,768	[illegible]	[illegible]	[illegible]	5,732,812	2,866,406	[illegible]	968,000	[illegible]	[illegible]	[illegible]
Minnesota	6,849,307	8,155,385	3,811,905	532.1	2,122,228	1,061,114	117.8	[illegible]	[illegible]	51.2	[illegible]
Mississippi	4,357,536				768,840	384,720	45.0	337,771	[illegible]	55.9	3,534,131
Missouri	7,601,200	3,992,349	1,992,287	435.8	[illegible]	3,225,855	240.7	[illegible]	1,357,17[illegible]	[illegible]	[illegible]
Montana	5,122,333	3,760,571	2,105,635	384.1	[illegible]	1,404,757	[illegible]	[illegible],237	[illegible]	29.2	[illegible]
Nebraska	[illegible]	2,740,846	1,363,005	170.2	2,902,737	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
Nevada	[illegible]	[illegible]	1,249,457	[illegible]	691,419	594,663	14.3	9,600	[illegible]	.8	[illegible]
New Hampshire	1,218,750	[illegible]	[illegible]	24.3	[illegible]	90,742	[illegible]	[illegible]	[illegible]		[illegible]
New Jersey	3,352,469	[illegible]	[illegible]	30.4	2,569,048	1,207,229	[illegible]	[illegible]	[illegible]		[illegible]
New Mexico	3,990,023	3,167,008	1,947,138	265.7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
New York	[illegible],710	[illegible]	[illegible]	148.4	13,740,944	[illegible],817,222	233.7	[illegible]	[illegible]	[illegible]	[illegible]
North Carolina	5,879,466	2,032,465	[illegible]	299.2	[illegible]	1,362,658	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
North Dakota	3,918,269				384,820	204,5[illegible]	.4				[illegible]
Ohio	9,131,204	2,334,794	1,166,992	40.9	[illegible]	[illegible]	[illegible]	[illegible],710	387,355	[illegible]	[illegible]
Oklahoma	[illegible]	2,435,519	1,204,426	82.3	2,011,130	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oregon	4,089,711	2,708,655	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pennsylvania	[illegible]	[illegible]	[illegible]	101.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Rhode Island	1,218,750	[illegible]	[illegible]	3.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
South Carolina	3,381,377	176,882	[illegible]	12.9	[illegible]	1,612,170	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
South Dakota	4,078,647	1,396,263	[illegible]	188.6	[illegible]	[illegible]	43.4	[illegible]	[illegible]	[illegible]	[illegible]
Tennessee	[illegible]	2,170,243	[illegible]	94.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Texas	[illegible]	[illegible]	[illegible]	604.0	[illegible]	2,651,430	252.5	[illegible]	[illegible]	71.7	[illegible]
Utah	[illegible],826,960	1,992,673	[illegible]	137.9	779,689	[illegible]	[illegible]	327,491	[illegible]	[illegible]	[illegible]
Vermont	[illegible]	[illegible]	[illegible]	62.9	[illegible]	354,748	20.2	[illegible]	[illegible]	[illegible]	[illegible]
Virginia	[illegible]	2,427,708	1,211,498	93.7	2,239,553	1,119,770	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Washington	3,904,738	[illegible]	1,908,735	148.1	2,195,186	1,153,071	84.8	[illegible]	[illegible]	[illegible]	[illegible]
West Virginia	2,716,754	477,989	[illegible]	28.0	1,124,522	562,249	32.0	[illegible]	[illegible]	[illegible]	[illegible]
Wisconsin	[illegible],090,504	4,102,133	[illegible]	164.7	3,833,485	1,862,474	129.5	[illegible]	[illegible]	18.7	[illegible]
Wyoming	3,121,972	2,830,630	1,741,663	367.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
District of Columbia											
Hawaii	1,218,750				537,793	[illegible],921	9.8	421,000	[illegible]	8.4	[illegible]
TOTALS	243,750,000	132,271,489	69,034,719	7,513.9	127,763,866	65,663,856	4,519.9	[illegible],197,544	[illegible]	[illegible]	[illegible]

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31 1936

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated cost	Works Program funds	Miles	Estimated total cost	Works Program funds	Miles	Estimated total cost	Works Program funds	Miles	
Alabama	$4,151,115	$2,419,252	$2,418,952	79.6	$1,017,653	$1,017,653	58.7	$34,000	$34,000		$80,310
Arizona	2,569,841	2,488,635	2,174,659	161.8	565,100	355,234	27.2				58,948
Arkansas	3,352,061	2,382,448	2,376,461	242.3	836,651	822,849	104.8	55,329	55,221	11.9	41,929
California	7,747,928	4,973,493	4,790,066	201.8	2,899,548	2,876,028	53.5				74,834
Colorado	3,395,263	1,992,021	1,885,276	93.1	239,476	239,470	11.0				1,270,518
Connecticut	1,411,709	280,605	273,273	2.9	407,298	401,565	5.8	297,181	297,131	8.9	380,693
Delaware	990,310	390,511	387,034	45.0	475,574	377,916	21.9				135,360
Florida	2,597,144	1,191,142	1,178,105	47.3	1,297,266	1,297,266	51.3	66,957	66,957	.4	64,815
Georgia	4,988,967	449,449	444,648	29.0	782,608	782,608	44.8	335,369	335,369	31.4	3,422,002
Idaho	2,222,747	2,111,190	2,043,061	173.7	135,387	135,387	9.5	19,658	19,658	2.4	24,642
Illinois	8,694,009	7,077,367	6,999,745	362.7	1,237,140	1,237,140	81.4	36,000	36,000	.1	21,123
Indiana	4,341,259	2,001,209	1,776,314	76.5	3,045,029	3,045,029	152.1	37,924	37,924	6.3	61,987
Iowa	4,391,604	2,446,516	2,442,431	322.7	3,573,799	3,540,723	172.4	37,723	21,450	2.9	
Kansas	4,354,275	2,157,310	2,154,950	226.1	2,840,316	2,821,762	145.0	6,600	6,600	.5	1,763
Kentucky	3,726,271	2,381,502	2,379,845	287.5	827,502	827,502	54.3	[illegible]	[illegible]	[illegible]	223,765
Louisiana	2,790,429	1,039,962	884,605	59.3	1,355,365	1,254,273	105.8	230,428	192,302	9.5	158,539
Maine	1,670,799	1,225,576	1,224,205	52.6	362,292	362,292	18.5	52,100	52,100	1.7	18,202
Maryland	1,750,738	261,307	261,307	14.6	629,100	599,745	12.3	549,422	449,556	14.2	439,629
Massachusetts	3,262,885	117,754	117,754	1.1	2,640,216	2,286,656	16.9	141,900	141,900	.4	716,375
Michigan	6,301,414	6,018,500	5,957,970	273.0	197,071	197,071	6.4	150,350	145,350	3.3	523
Minnesota	5,277,145	5,107,678	4,323,352	807.9	1,225,175	921,200	93.7	137,137	120,248	2.7	7,345
Mississippi	3,457,552	1,703,752	1,690,701	123.2	1,476,644	1,475,275	91.1	220,759	220,759	17.8	61,917
Missouri	6,012,652	3,401,605	3,370,237	695.8	2,265,859	2,149,902	80.3	597,073	429,968	1.7	62,544
Montana	3,676,416	3,388,933	3,388,267	135.1	244,036	236,066	10.2				52,034
Nebraska	3,370,739	2,232,400	2,119,164	240.1	1,315,462	1,313,958	117.6	117,394	117,394	12.2	249,723
Nevada	2,243,074	1,752,455	1,704,805	79.4	266,225	266,225	12.0	21,998	21,998	.6	250,046
New Hampshire	945,225	576,606	551,621	24.6	257,992	255,249	9.8	36,683	36,583	.5	101,772
New Jersey	3,129,805	652,052	652,052	14.0	2,218,278	2,202,125	15.1	194,056	185,087	4.7	90,543
New Mexico	2,871,397	2,031,276	2,030,572	153.4	605,168	605,168	34.8	93,636	93,636	5.2	92,021
New York	11,046,377	6,822,509	6,535,331	128.8	4,295,350	4,197,450	33.0	328,700	328,700	2.5	14,895
North Carolina	4,720,173	1,816,868	1,816,368	117.6	2,664,760	2,601,571	159.9	177,371	141,431	10.0	160,303
North Dakota	2,867,245	1,361,931	1,360,193	206.0	1,150,996	1,147,560	99.6	159,611	159,611	20.2	199,880
Ohio	7,670,815	2,733,841	2,701,278	106.8	3,779,307	3,700,911	132.4	1,123,660	1,120,130	58.2	148,496
Oklahoma	4,580,670	2,088,417	2,077,953	135.1	1,651,715	1,650,119	171.0	618,286	606,299	36.3	246,299
Oregon	3,038,642	2,054,423	2,035,590	149.3	1,161,327	799,892	8.0	69,992	69,992	9.5	133,169
Pennsylvania	9,347,797	1,552,018	1,490,359	77.4	2,140,556	2,090,718	56.2	1,906,721	1,900,907	62.2	3,805,813
Rhode Island	989,208	990,131	979,535	18.8				9,673	9,673		
South Carolina	2,702,012	846,994	800,528	84.8	1,406,463	1,357,932	131.8	257,317	244,009	16.3	299,543
South Dakota	2,976,454	1,902,992	1,902,393	372.4	797,827	797,827	91.1	106,870	106,870	18.2	169,364
Tennessee	4,192,460	2,079,079	2,072,209	85.3	994,961	994,961	38.4	511,050	511,050	18.9	614,240
Texas	11,939,350	9,734,549	8,834,417	894.1	3,290,763	3,011,798	217.8	188,047	89,975	10.0	53,161
Utah	2,067,154	1,505,860	1,369,436	158.1	545,041	513,678	31.6	90,221	90,221	3.5	93,819
Vermont	924,306	842,732	741,059	20.5	178,368	142,065	1.2	33,020	19,910	.4	21,272
Virginia	3,652,667	2,736,504	2,661,344	860.1	690,775	677,701	155.1	135,181	135,181	27.6	178,442
Washington	3,026,161	2,509,038	2,278,785	157.7	892,267	747,376	6.9				
West Virginia	2,231,412	396,480	393,276	22.0	1,680,051	1,679,711	67.6	92,170	61,438	.9	96,987
Wisconsin	4,823,884	4,793,904	4,261,018	312.8	699,752	542,287	30.4				20,579
Wyoming	2,219,155	1,598,113	1,598,095	123.1	601,745	582,876	17.0				38,184
District of Columbia	949,496	930,398	930,398	8.6	25,600	362	.2				18,735
Hawaii	926,033	244,040	228,809	4.0	401,856	395,297	4.9	286,422	285,884	8.4	16,044
TOTALS	195,000,000	113,831,069	109,211,247	9,204.0	65,068,041	61,934,135	3,116.9	9,964,822	9,359,841	447.9	14,494,777

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31,1936

STATE	APPORTIONMENT	COMPLETED		NUMBER			UNDER CONSTRUCTION		NUMBER			APPROVED FOR CONSTRUCTION		NUMBER			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Work Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Fund	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 1,360,021	$ 1,360,021	20		4	$ 2,409,673	$ 2,409,673	28			$ 44,867	$ 44,867	1		8	$ 220,057
Arizona	1,256,099	618,960	614,725	7			566,261	554,816	6								86,558
Arkansas	3,574,060	1,271,375	1,267,250	29	4		1,651,166	1,648,268	21	2		487,346	486,541	7		29	171,901
California	7,486,362	3,494,543	3,373,754	21	7		3,919,677	3,796,182	23	1							316,426
Colorado	2,631,567	1,076,063	1,055,063	20			847,708	847,699	7	1		284,733	284,732	3			444,073
Connecticut	1,712,684						713,457	647,379	4	1	1	261,044	261,044		2		804,261
Delaware	418,239						143,486	120,000	1								298,239
Florida	2,827,883	994,679	992,948	7	5		1,276,024	1,275,101	20	1		223,200	223,200	2			331,634
Georgia	4,895,949	12,090	12,090	1			422,593	422,593	8	2		481,243	481,243	16			3,979,723
Idaho	1,674,479	896,716	893,543	14	1	1	374,017	373,903	6		1	25,265	25,265			15	381,767
Illinois	10,307,184	2,912,631	2,912,094	40			5,626,077	5,455,790	28	5		1,901,700	1,901,700	8	2		37,600
Indiana	5,111,096	1,034,272	1,034,272	16	3		3,836,317	3,713,098	27	8		399,720	363,120			162	6
Iowa	5,600,679	1,696,581	1,649,719	45	6		3,668,194	3,632,943	58	3		371,051	255,950	4		8	62,032
Kansas	5,246,258	774,057	774,057	11		3	4,490,555	4,425,590	45	1		46,511	46,511	2		1	
Kentucky	3,672,387	265,336	265,336	7	1		2,462,277	2,173,545	13	2		184,391	184,391	3	3		1,049,115
Louisiana	3,213,467						1,447,148	1,447,148	14	1		955,512	922,045	8	7		841,272
Maine	1,426,861	497,560	497,227	12		2	584,695	584,103	8			77,464	77,464	1			[illegible]
Maryland	2,061,751	274,706	274,706	2	3		595,123	595,123	3		11	644,080	621,611	[illegible]	2	8	[illegible]
Massachusetts	4,210,533	498,005	498,005	4	2		2,450,301	2,450,301	19	1		243,931	243,931	1			1,012,536
Michigan	6,765,197	3,167,975	3,123,475	33	4		3,602,197	3,602,197	12	4							39,525
Minnesota	5,395,441	2,846,593	2,715,679	60	9	38	2,509,840	2,323,459	25	3	3	58,428	58,428		1	1	297,875
Mississippi	3,241,475	617,911	617,911	18	3	1	1,943,378	1,943,378	35			33,400	33,400			3	646,786
Missouri	6,142,153	308,981	308,981	6			5,595,929	5,499,585	46			367,251	253,300	1		2	80,187
Montana	2,722,327	2,475,015	2,475,015	35	6		178,582	178,582	2								68,730
Nebraska	3,556,441	1,524,429	1,523,107	57	1	1	1,523,787	1,523,787	21	1	5	433,559	433,559	5	1	19	75,988
Nevada	837,260	690,198	690,198	9	1		211,658	193,432	1			3,630	3,630			5	
New Hampshire	822,424	341,749	341,748	3	3		160,490	160,490	4	1	1	264,177	264,132	3			56,114
New Jersey	3,983,826	233,331	233,331	1	2		2,305,294	2,294,249	16			305,279	305,279	3	2		1,150,967
New Mexico	1,725,236	665,807	665,807	12			1,062,169	1,059,479	7	1							
New York	13,577,189	2,070,973	2,066,173	11	8		9,688,551	9,432,605	29	30		334,720	334,720		5		1,743,591
North Carolina	4,323,958	676,700	676,700	11	7		2,539,248	2,523,748	27	6	46	730,180	730,180	10	1	15	843,330
North Dakota	3,207,473	434,386	434,386	14			1,849,657	1,849,657	29	3		657,820	657,820	15	1		265,510
Ohio	8,439,897						4,768,797	4,543,193	29	5		3,138,670	2,976,512	23	2	3	920,092
Oklahoma	5,004,711	1,234,711	1,234,711	26	2		1,892,426	1,892,426	22	2		522,967	522,967	6	4		1,354,507
Oregon	2,334,204	841,368	841,329	8	5	2	1,528,723	1,447,128	8	1		34,950	34,950	1			[illegible]
Pennsylvania	11,483,613	674,465	607,001	21	1		6,896,137	6,360,721	44	13	9	2,141,769	2,031,469	7	3		2,454,423
Rhode Island	699,591	398,464	398,464	2	1		277,305	276,739	2	1							24,438
South Carolina	3,059,956	482,776	475,124	12	2	3	1,400,825	1,389,482	25	7		242,303	242,303	1		51	952,547
South Dakota	3,249,036	630,112	630,112	18	1	11	1,556,719	1,556,719	37	2	14	239,025	239,025	8	1	6	773,230
Tennessee	3,903,979	358,211	358,211	6	1	10	1,547,863	1,547,863	25	1	3	720,356	720,356	7	1	9	1,277,550
Texas	10,855,982	3,066,914	3,066,913	52	9		6,673,820	6,667,443	75	4		679,547	679,541	2	1	176	442,056
Utah	1,230,763	87,218	85,828	1	1		1,109,086	1,092,438	16			2,400	2,400			1	50,096
Vermont	729,857	479,951	474,639	7	5	9	191,630	176,930	1	1	3	58,500	29,000	2		2	49,288
Virginia	3,774,287	1,321,875	1,251,010	26	5		953,598	914,599	12	7		501,186	501,185	12	2	11	1,107,493
Washington	3,095,041	869,998	865,167	15	3	5	1,966,931	1,956,506	8	8	1	9,967	9,967			3	253,401
West Virginia	2,577,937						1,332,633	1,332,631	17	2		371,232	371,232	4	1	4	974,073
Wisconsin	5,022,683	1,896,054	1,867,957	24	4		3,077,522	2,979,068	13	3							175,558
Wyoming	1,360,841	355,507	355,400	5			758,835	725,932	7								281,609
Dist. of Columbia	410,804						425,564	396,704	3								14,000
Hawaii	453,703						522,330	453,703	5								
TOTALS	196,000,000	46,429,767	45,859,187	749	116	90	107,644,828	104,876,133	943	138	98	18,506,144	17,970,961	168	38	542	27,293,819

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF DECEMBER 31 1936

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	[illegible] 1934 Funds	[illegible] 1935 Funds	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ [illegible]	$ [illegible]	$ [illegible]	$ [illegible]	$ 3,713,718	[illegible]	$ 234,709	$ 52,565	$ 232,044	[illegible]		$ [illegible]	1.5	$ 16,076	$ 21,258
Arizona	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12,500		12,500					7,448	24,400
Arkansas	[illegible]	[illegible]	[illegible]	[illegible]	3,347,140	[illegible]	[illegible]	70,019	43,836	3.4	$ 39,772	[illegible]	14.0	7,059	9,988
California	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]					24,932	46,567
Colorado	[illegible]	[illegible]	[illegible]	[illegible]	3,441,857	[illegible]	[illegible]		[illegible]					3,849	37,530
Connecticut	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		.1				47,854	142,098
Delaware	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	122.3	[illegible]		[illegible]	[illegible]				284	[illegible]
Florida	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	4.0	56,300		.5		18,016
Georgia	[illegible]	[illegible]	13,271,965	[illegible]	[illegible]	760.8	[illegible]	[illegible]	[illegible]	74.3	84,072	160,700	[illegible]	[illegible]	[illegible]
Idaho	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54,193		[illegible]	.1	60,772	1,886	.9	[illegible]	32,050
Illinois	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	712.3	[illegible]	[illegible]	[illegible]	11.2	37,390	7,100	12.8	[illegible]	[illegible]
Indiana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.6		[illegible]		[illegible]	[illegible]
Iowa	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	5.1	[illegible]				
Kansas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	13.1				4	[illegible]
Kentucky	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	4.2	8,569	[illegible]		1,649	8,694
Louisiana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	258,115		[illegible]	11.5		72,939	.1	41,034	[illegible]
Maine	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15,000	15,000				26,540	1.4	8,033	8,738
Maryland	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	162,147		161,772	5.3		235,453	7.3	[illegible]	352,376
Massachusetts	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	.1	44,366	[illegible]
Michigan	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	1.2		40,000	.4		[illegible]
Minnesota	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58,110	[illegible]	7.2		34,300	[illegible]	84,037	[illegible]
Mississippi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	723.3	[illegible]	[illegible]	464,865	20.8	3,960	[illegible]	1.9	[illegible]	[illegible]
Missouri	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,130,934		1,127,050	6.4		62,100		[illegible]	60,939
Montana	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]					[illegible]	11,999
Nebraska	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	27.7		63,537	5.9	[illegible]	21,800
Nevada	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	25,004		25,004			[illegible]			7,111
New Hampshire	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4,174		4,174					4,888	14,793
New Jersey	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85.9	[illegible]	[illegible]	[illegible]	10.3	[illegible]	[illegible]	.6	97,724	[illegible]
New Mexico	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	743.9	107,130		107,130	5.9		2,695		[illegible]	[illegible]
New York	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.7	127,947	119,856	1.3	27,419	[illegible]
North Carolina	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,345.8	[illegible]	291,910	[illegible]	15.3		200,000	4.3	[illegible]	[illegible]
North Dakota	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2,127.0	[illegible]	[illegible]	124,120	[illegible]	15,703	[illegible]	27.9	65,418	400,415
Ohio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.3	34,023	[illegible]	[illegible]	24,114	54,817
Oklahoma	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	805.5	[illegible]		[illegible]	1.1		174,301	.2	3,226	91,865
Oregon	[illegible]	[illegible]	[illegible]	[illegible]	2,940,828	468.0	75,530	11,308	64,222	.8		[illegible]		58,391	[illegible]
Pennsylvania	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.8	[illegible]	149,500	3.9	148,620	317,063
Rhode Island	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]									2,478
South Carolina	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	160,231	127,073	8.7	[illegible]	122,701	2.8	14,719	74,680
South Dakota	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	130,334	27.0		12,161	[illegible]	[illegible]	45,364
Tennessee	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		173,372	4.0		[illegible]	5.9	1,913	14,525
Texas	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.1	12,000	[illegible]	9.3	39,564	124,904
Utah	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32,292	[illegible]					1,500	
Vermont	1,847,573	[illegible]	[illegible]	[illegible]	[illegible]	141.0								121	5,337
Virginia	[illegible]	[illegible]	[illegible]	[illegible]	3,410,560	[illegible]	[illegible]	[illegible]	[illegible]	30.5	7,035	59,917	[illegible]	[illegible]	87,970
Washington	[illegible]	[illegible]	[illegible]	6,112,042	3,007,370	[illegible]	[illegible]		[illegible]			14,823	.3	3,825	17,622
West Virginia	4,474,234	[illegible]	[illegible]	[illegible]	[illegible]	211.1	[illegible]	83,534	460,028	11.4		[illegible]	.7	76,951	117,140
Wisconsin	9,724,281	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		4,176	2,720			37,613
Wyoming	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,037.7	[illegible]	5,780		.3		21,300		43,624	37,712
District of Columbia	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	22.3									4,863
Hawaii	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51.1	650,838		[illegible]	4.8		14,000		13,250	23,966
TOTALS	394,000,000	200,000,000	[illegible]	[illegible]	[illegible]	35,025.8	[illegible]	2,790,763	10,669,781	366.0	770,933	[illegible]	124.6	1,719,550	4,464,037

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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 17, NO. 12 FEBRUARY 1937

NATIVE PLANTING ON SLOPES INACCESSIBLE TO MECHANICAL MOWERS ON ROAD NEAR ELDORA, IOWA

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PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the
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BUREAU OF PUBLIC ROADS

Volume 17, No. 12 February 1937

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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WEED CONTROL AND ERADICATION ON ROADSIDES

A STUDY OF PRESENT PRACTICES AND THEIR PRACTICAL APPLICATION

Reported by **O. K. NORMANN**, Assistant Highway Engineer, Division of Construction, Bureau of Public Roads

A, Uncontrolled Weed Growth on the Roadside. B, Pleasing Appearance of a Roadside Where Weeds Are Controlled.

WEED CONTROL and eradication on roadsides is an important function of State and local road maintenance organizations. One midwestern State highway department has spent an average of $639,286 per season or 18.8 percent of its total maintenance expenditures during the past 3 years for eliminating and controlling undesirable weed growth along State highways.

The increasing demand for broad, well-kept highways on ample rights-of-way has given increased importance to the problem of weed control and eradication. Without adequate methods of eradicating or controlling weeds it is not possible to have roadside attractiveness developed to its full extent. Simplicity and neatness are among the first requirements in roadside treatment. A rank growth of tall weeds may partake of simplicity but such a growth continuously along the highway can never be neat.

During the fall of 1935 a survey was begun by the Bureau of Public Roads to obtain data on the weed-control practices of each State highway department and other agencies. A compilation of such information should be useful to maintenance organizations in more effectively meeting the problems involved.

Reports were received from maintenance engineers covering the procedure, cost, effectiveness, and extent of weed prevention and eradication methods in use by all State highway departments. Information was also obtained from leading authorities on weed control either through correspondence or review of their publications. After a detailed study and analysis of all available material, this report, covering mowing, blading, burning, tillage, planting of smother crops, and application of herbicides, was prepared.

A road supervisor or patrolman directing operations to control or eradicate weeds should first observe and classify existing vegetation to determine the types to be considered weeds, as judged by their advantages and disadvantages. It is usually possible then to plan field operations that will tend to discourage or eliminate objectionable types and leave unharmed or encourage preferred types of growth.

By definition a weed is "any harmful or useless plant; a wild plant which hinders the growth of cultivated ones; anything useless or troublesome." Any plant that is or may become undesirable in its particular location, injurious to crops, or people, can be considered a weed. A plant that is very useful in one location may be harmful in another. In the United States poppies are not considered weeds, yet in France they have become one of the worst weeds.

Weeds on roadsides help to prevent erosion by water, wind, or traffic. Their usefulness in this respect may easily be overestimated unless other factors are considered. Most weeds, particularly those on newly constructed roads, are annuals having a luxurious top growth during the late spring and summer months. Their root systems, however, do not afford the same protection as the more extensive root systems of perennials. From late fall to well into the spring months, the period of greatest erosion in most localities, root systems of annuals afford little protection.

Recent studies by the United States Department of Agriculture have shown that for each climatic or soil condition there is a type of desirable vegetation that requires little or no encouragement to grow and that will prevent soil erosion equally as well as undesirable varieties do. The pioneering annual or early ruderal types of vegetation are usually most valuable as temporary forerunners of more permanent plants that are desirable as ground-cover protection. Weeds give way to more desirable vegetation on roadsides where proper maintenance methods are practiced.

WEED CONTROL ESSENTIAL FOR WELL-KEPT ROADSIDES

Every State highway department has the objective of keeping its roadsides free from trash and debris, neatly mowed, and of a generally pleasing appearance.

Extensive planting and landscaping cannot be done immediately on all the main highways but clean-up of debris and control of undesirable growth is a possibility on all main roads and on many secondary roads. The improved appearance of roadsides produced by weed control is sufficient to warrant the expenditures made and the highway officials need seek no further for justification. However, there are a number of other benefits.

Some of these benefits relate to the highway itself. Tall weeds may lessen the sight distance on curves and at intersections. Even low-growing weeds may hide culvert headwalls, guardrails, markers, and other obstructions. Culverts and drains may become clogged with weed growth causing washouts or other damage.

Weeds may cause drifting of snow, and in a few areas the drifting of soil, that blocks the highway. They may also cause desirable drifting that protects the road. In such cases a permanent planting of selected material is to be recommended in place of the weeds.

Weed control on highways is of definite benefit to agriculture. Seeds from uncontrolled weeds on the roadside are continually carried to adjacent fields by wind, water, and birds. Passing automobiles carry them to distant points to infest new areas. Agricultural specialists and progressive farmers attach considerable importance to the control of weeds along fence rows and roadsides. Laws have been enacted in many States making highway officials responsible for destroying weeds but these laws are seldom rigidly enforced. The spread of any kind of weed to farm fields is damaging and certain kinds of weeds have rendered valuable land almost worthless.

Weeds such as wild lettuce, Russian thistle, dock, and wild mustard often harbor insects that invade field crops during certain seasons. The weeds shelter the insects during the winter months when they might otherwise be destroyed.

The pollen from some weeds causes hay fever. Contact with poison ivy, and poison oak, often results in severe skin injury.

Dry weeds are a fire hazard to adjacent fields, woods, and structures. The hazard is accentuated by the danger of burning cigarettes and cigars thrown from cars.

That weed control is desirable is now generally accepted among highway officials and some effort at control is made on practically all of our main highways. However, the effort is not always made at the right time or by the best methods. It is believed that wherever control is attempted, it should be made sufficiently effective to prevent reproduction of undesirable growth, thus lessening the amount of future control work.

In deciding upon the most effective or practical method of control it is necessary to consider the weed's habits, habitat, and distribution. It is important to know the time and conditions under which seeds germinate; how much time is required to mature seeds; whether the plant dies at the end of 1 or 2 years, or lives several years; and whether it reproduces and spreads only by seeds or also by vegetative propagation. Such information will often enable the supervisors and patrolmen to check or stop natural reproduction of weeds.

Weeds may be classified into four general groups as follows:

1. *Annuals.*—Plants that complete their growth and die in 1 year. They depend upon seeds for reproduction. Examples are puncture vine, ragweed, Russian thistle, and wild oats.
2. *Winter annuals.*—Plants having seeds that germinate in the fall and complete their growth the following spring. Examples are chickweed and shepherd's purse.
3. *Biennials.*—Plants that require 2 years to complete their growth, storing up food during the first year and completing growth and seeding the second year. Most biennials depend entirely upon seeds for propagation. Examples are bull thistle, burdock, and wild carrot.
4. *Perennials.*—Plants that live 3 or more years and reproduce from both seeds and roots. Examples are bindweed, Canada thistle, dock, oxeye daisy, and Johnson grass.

SEVERAL METHODS USED TO CONTROL AND ERADICATE WEEDS

Annuals, winter annuals, and biennials can be effectively controlled and finally eradicated by preventing the formation of seed. Methods that will kill the roots must be used to eradicate perennials, but preventing the formation of seed will help confine them to a limited area.

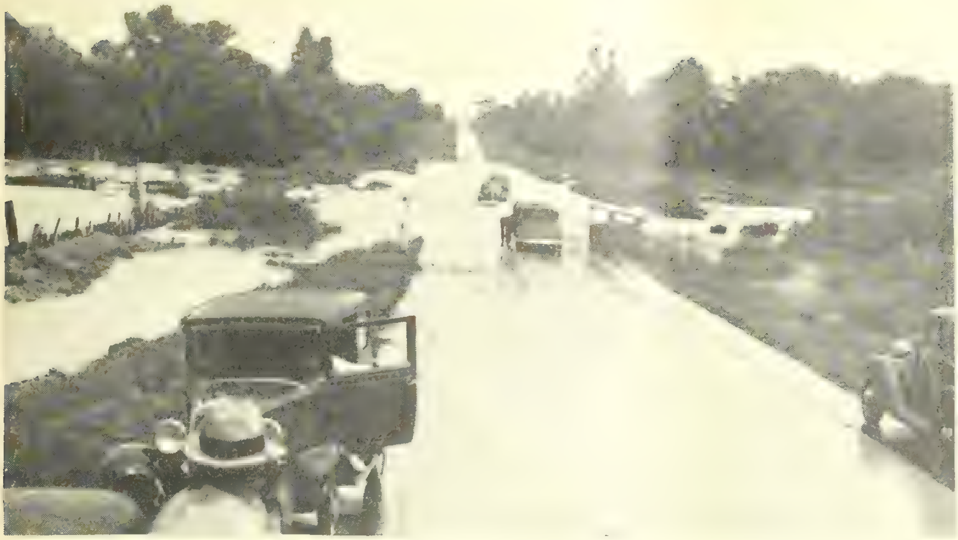
Methods for controlling weeds are mowing, burning, blading, dragging, steaming, hand pulling, hoeing, smothering, and killing with herbicides. Each of these methods has certain advantages and disadvantages that must be considered before it is possible to determine the most effective method to use under given conditions. Maintenance personnel must recognize fully the importance of all factors that influence the effectiveness of the various methods and must take advantage of all favorable conditions to make the methods used as efficient as possible.

Timely mowing is an effective method of controlling most annual weeds. By thus preventing seeds from maturing, their only means of propagation is destroyed. Mowing is the most practical method of discouraging objectionable weed growth and encouraging desirable permanent types of vegetation on roadsides and large areas where funds for weed eradication are very limited.

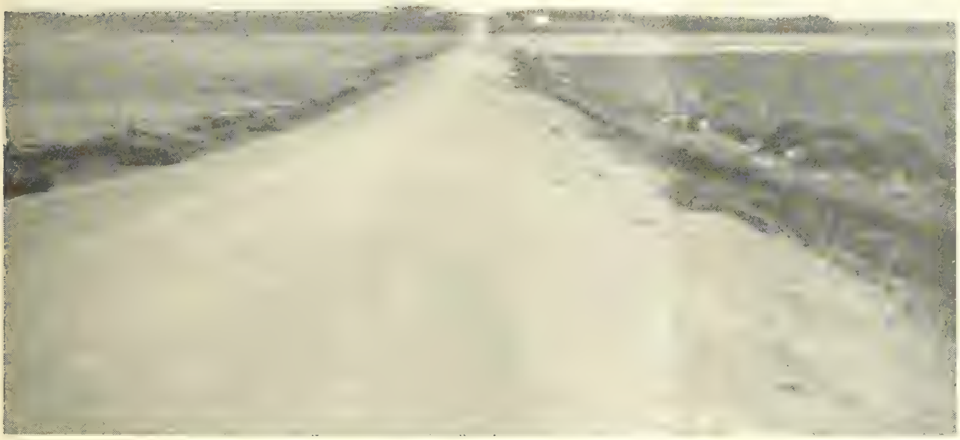
Complete eradication of perennial weeds by mowing is difficult, and satisfactory results are obtained only by monthly cuttings during the growing season over a period of years. Mowing often enough to prevent the formation of seed will confine the perennial weeds to a limited area.

Unless mowing is done at the proper time, it may actually spread the growth of weeds. As a rule, it is best to mow when weeds have reached the bloom stage. All too frequently weeds are mowed when they are in seed and the plants are left on the ground to dry. The flowers of many plants are formed over a period of several weeks, and although the plant has the appearance of being in flower, it may have mature seeds or seeds developed far enough to mature. Early destruction is desirable if reseeding is to be prevented. It is impossible to specify the best date for the mowing of all weeds in all localities, as different species produce seeds at different seasons and the same species mature at different dates in various locations. For this reason, each highway patrolman or supervisor should be familiar with the weeds in his section and should know the proper time to cut or destroy the weeds of each variety to prevent seed formation.

Mowing the roadsides one or more times each season is a common procedure and in many States this is all that is done to control weeds. The number of mowings



Overflow Caused by Weeds and Silt Blocking Ditch on Left Side of Roadway.



Tumbleweeds Caught Along Fence Lines May Cause Snowdrifts Across the Roadway During Winter Months.

Ditches Filled with Drift Sand and Soil Deposited Along Fences Where Tumbleweeds Were Allowed to Collect.

WEEDS MAY MAKE ROADS IMPASSABLE BY CAUSING WASHOUTS, SNOWDRIFTS, OR DEPOSITS OF SAND AND SOIL.

Weeds May Become a Menace to Traffic: A, by Reducing the Effectiveness of Guardrail; B, by Concealing Markers and Obstructions Outside the Traveled Way; and C, by Shortening Sight Distances at Curves.

per season, the width covered, and the main purpose of the mowing operations vary greatly between States. The number of mowings varies from 1 to 8; the width varies from one swath on the shoulders to the entire right-of-way.

The general practice by a majority of highway departments is to mow and remove weeds in the fall during the yearly clean-up of the entire right-of-way after the weeds have completed their growth. This clears the roadside of dead growth that might clog the ditches and culverts and cause formation of snowdrifts on the roadway during the winter and spring months, but helps very little in the control or permanent eradication of undesirable vegetation.

In addition to mowing over the entire right-of-way in the fall, the majority of State highway departments also mow over the shoulders one or more times during the growing season. A few mow over the entire right-of-way 2 or 3 times, the shoulders 4 to 8 times, and supplement these mowings by hand cutting of weed patches as needed to keep seeds from maturing.

The equipment used for the mowing operation includes truck- or tractor-drawn hay mowers, power mowers, ordinary horse-drawn farm mowers, and hand scythes. When mechanical mowers are used, weeds around headwalls, guard rails, fences, signs, highway markers, and other obstructions where the mechanical unit cannot be used are cut by laborers using scythes.

The most effective type of mechanical mowing unit depends largely upon the width and roughness of the roadside to be cut over and the number of headwalls, highway markers, or other obstructions present. The type preferred by maintenance superintendents in a majority of States, especially when cutting over the entire right-of-way, is the common, horse-drawn farm mower. Two of the reasons for this preference as given by men in charge of maintenance operations on State highways are as follows:

1. The units can be operated efficiently over comparatively rough ground and close to obstructions, thus reducing to a minimum the amount of hand work required.
2. Farm-owned mowers can be rented at reasonable rates, thus reducing the amount of State-owned equipment required and efficient operators experienced in maneuvering mowers in and out of ditches and over rough slopes can usually be hired from local farms.

The horse-drawn farm mower costs less to operate and the consensus of opinion is that better work is done than with other types of mowing units.

MECHANICAL MOWING CHEAPER THAN HAND MOWING

Hourly rates for hired mowers, including two horses and the operator, varied from 60 cents to 1 dollar during 1935 in the States that furnished cost data for this operation. The resulting costs varied from $1.20 to $2.43 for a round trip over 1 mile of highway or $0.99 to $2 per acre. One State hiring mowers on a mileage basis paid $1.30 per round trip over 1 mile on old roads and $1 on roads recently graded where the cutting was easier because of modern design.

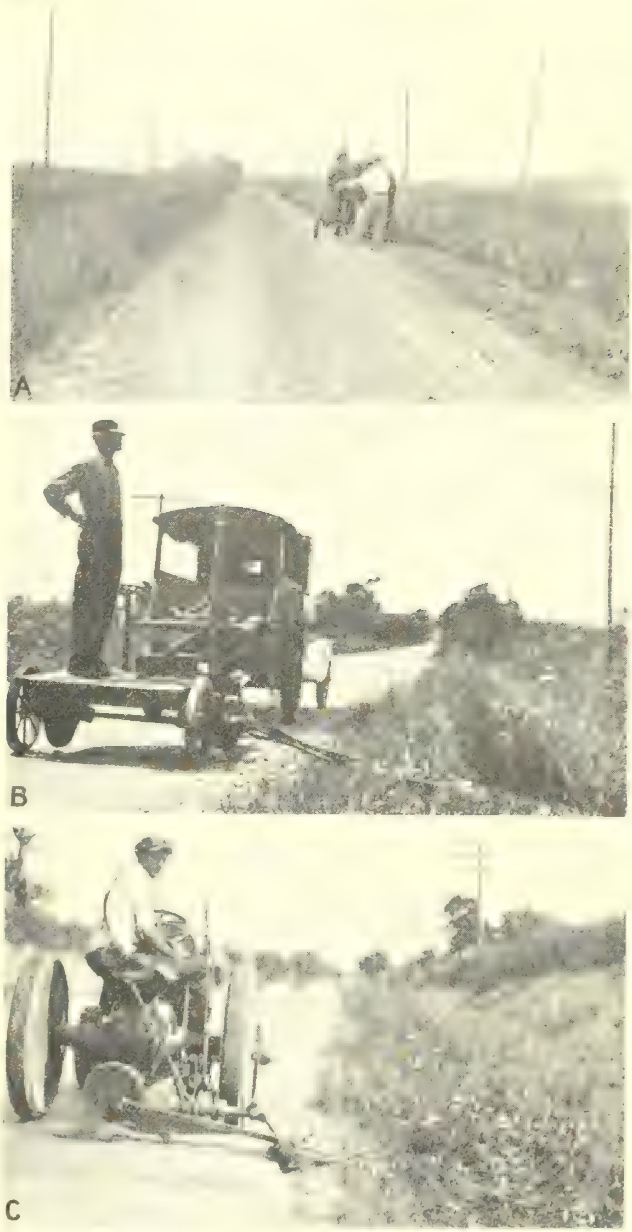
Mowers drawn by light trucks are very effective on shoulders and other places where there are few obstructions. Some States, however, prefer to use two mowers drawn by a light tractor as they have found that truck gears require frequent replacing when the truck is used continuously at speeds of 4 or 5 miles per hour. One man is able to operate a tractor and mower unit while two are usually required with a truck unit.

Numerous special types of self-propelled machines have been built by State forces for cutting roadside weeds. These include mowers attached to tractors with power take-offs and mowers attached at the side of a truck. Equipment manufacturers have also placed on the market several types of self-powered mowers especially designed for roadside work.

All of the self-powered units and truck-drawn mowers have been tried by various State highway departments. Many have been discarded in favor of the horse-drawn mower. In sections where it is impossible to obtain sufficient teams when desired, the power units have been developed to a point where they are considered very satisfactory.

Hand mowing with labor at $0.40 per hour costs about $5 per acre. This is considerably higher than the cost of cutting with horse-drawn or engine-powered

A, Cutting Weeds by Hand Around Obstructions and on Slopes Inaccessible to Mechanical Mowing Units. B, Cutting Patches of Weeds Before They Form Seed and Spread to Adjoining Fields.



A, the Horse-Drawn Farm Mower is Still the Most Commonly Used Mowing Unit on Roadsides. B, Mower Being Pulled by a Light Truck. C, Tractor With Power Take-Off for Operating Mower.

mowers. Some States prefer to use mechanical units on accessible sections first and then finish with hand scythes. Others precede mechanical mowing with hand cutting around all obstructions, trees, and desirable plants so that they will be in plain view of the operators of mechanical units.

Recent designs for highway cross sections have features, intended primarily to improve roadside appearance, that greatly facilitate mowing. Flatter slopes and rounded shoulders, gutters, and ditches have made a greater portion of the rights-of-way accessible to mechanical mowers.

Cooperation between maintenance personnel and landscape engineers is essential for economical roadside development. Volunteer growth that will develop into good shade or ornamental trees can be saved during the mowing operation if they are properly identified. Arranging roadside plantings so that weeds can be cut with a minimum of hand work will help materially in developing roadsides without increasing expenditures for grass and weed cutting.

Some States prefer to mow roadside weeds frequently, the cuttings being left on the right-of-way. Where tumbleweeds are removed from shoulders primarily to prevent snow drifts, cutting to pieces with a disk harrow has been satisfactory. Leaving vegetation to decay increases the fertility of the soil and eliminates damage from burning, provided accidental burning does not occur.

Weeds can be burned with a flame while they are green, as they stand after forming seeds, in piles after being cut, or after being sprayed with gasoline, oil, or other herbicides. Adequate control is assured if both plants and seeds are destroyed. The principal objections to burning are the fire hazard, particularly in timbered and grain-raising country, and the hazard to traffic from blinding by smoke.

Special care must be taken to see that adjoining property, fence posts, trees, etc., are protected, and provision must be made for warning traffic.

There are two general types of burners for green vegetation—the oven burner and the extended burner. The oven burner confines the heat and flame in an oven which is mounted on wheels or on the side of a truck. The extended burner is equipped with one or more burners on extended arms which may be operated individually or collectively and are controlled by the operator. Single burners are manufactured that will

Dual Mowers Pulled by Tractor.

shoot a flame for several feet and can be carried and operated by one man. These have been found to be useful in burning small scattered patches of weeds.

To be effective, burning should give the vegetation a thorough scorching. The great amount of heat required makes burning impractical on large areas of green weeds over 6 inches high.

Burning is a method of last resort applicable to roadsides on which weeds have been allowed to mature a crop of seeds. Dry weeds with attached seeds are best burned as they stand. Mowing before burning merely scatters the seeds and those on the surface of the soil are seldom exposed to a sufficiently high temperature to be destroyed.

After mowing dense vegetation or weeds that are beyond the full-bloom stage, it is advisable to pile and remove them from the roadside to prevent clogging of drainage facilities and the ripening of seeds starting to mature. Burning the piles when dry is the cheapest method if it can be done without injuring desirable growth or causing unsightly scars along the right-of-way.

SPECIAL PRECAUTIONS NECESSARY WHEN ROADSIDE WEEDS ARE BURNED

It is also possible to burn green weeds after spraying with oil or killing with certain herbicides.

Present burning practice of the State highway departments is extremely varied. Some departments, Indiana for example, allow no burning on the right-of-way because of the danger to traffic. The majority of the departments do allow burning on the right-of-way, especially when the growth is heavy, but issue detailed instructions to the patrolmen prescribing methods that must be followed to safeguard persons and property.

Burning is accomplished in New Mexico and Nevada by a steel drag with a fire ball attached that is pulled along the shoulders and ditches by a truck. The fire ball sets the loosened weeds on fire as it moves along. Old tires are sometimes used as the kindling material.

New Jersey permits burning only in the spring while the ground is still wet enough to protect the grass roots. Minnesota permits burning only on sandy areas, because of the danger of peat-bog fires, and only after May, so that nests of partridges and pheasants on the right-of-way will not be destroyed.

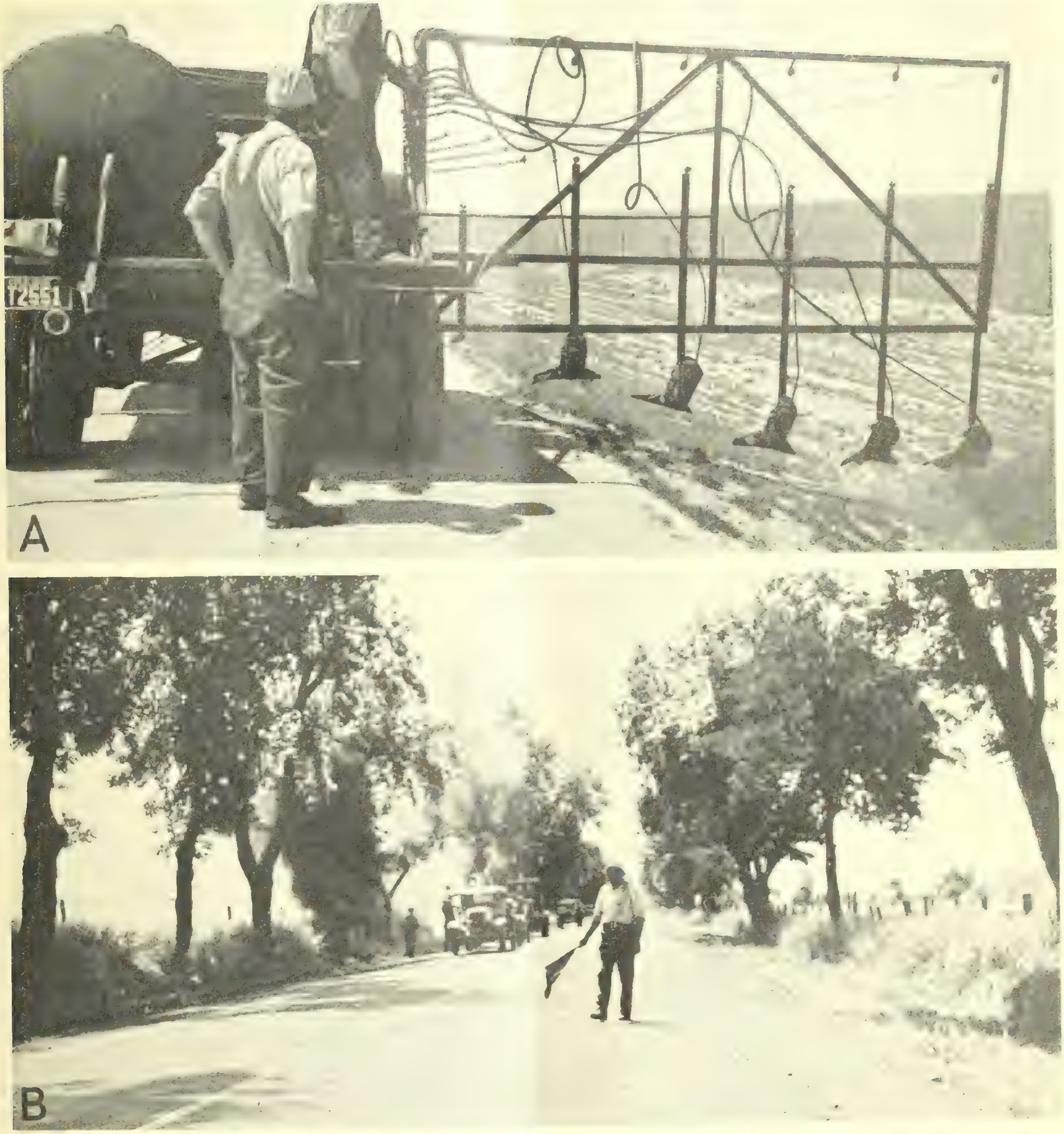
Below are listed a few of the suggestions in regard to burning operations as given by State highway officials to patrolmen in States where burning is allowed:

1. Unless there is a natural firebreak adjoining the right-of-way, burn only on the windward side of the highway so that the road surface will act as a firebreak. This necessitates exposing motorists to smoke and fumes.
2. Make adequate provision for warning traffic to slow down and stay on the right side of the road while passing through smoky areas.
3. Conduct the burning operation in such a manner as to avoid the formation of dense smoke.
4. Make adequate provision for protecting desirable vegetation from intense heat.
5. Any burning with mobile equipment should be closely followed by fire-extinguishing equipment. This is best done by a patrol equipped with knapsack fire extinguishers or a tank truck with sufficient water hose to reach beyond the area being burned.
6. In forest areas, cooperation between patrolmen and forest rangers is highly desirable.

Only three States reported the cost of burning operations. These are listed below:

California—Burning vegetation about 2 weeks after treating with oil costs $20 per mile for two 9-foot strips.

New Mexico—One man at 40 cents per hour can burn tumbleweeds on both sides of one-half of a mile of road in 1 day at a cost of $3.20. With a drag and



Burning Weeds Along Highways. A, Mechanical Weed Burner; the Individual Oil Burners Can Be Operated Singly or Collectively. B, Warning Traffic of Weed-Burning Operations, Which Are Hazardous to Both Traffic and Desirable Vegetation.

truck costing $7 per day and two men to control the burning and each paid 40 cents per hour, the cost was $4 per acre.

Idaho—The cost to pile weeds ready for burning was $5 per mile of road.

The cost of using burners on 24,618 miles of single track by five railroads during 1934 averaged $4.47 per mile including all labor, materials, equipment, and overhead charges.

Blading.—While scraping with a blade grader is considered to be an inexpensive means of destroying numerous young weeds on the roadside, it serves only to spread the plants if done after seeds are formed. Any blading operation has the disadvantage of disturbing and loosening the soil to wind and water erosion so that the ultimate cost, considering damage done and discomfort caused by the dust, may well exceed the cost of more satisfactory methods. Blading mixes the weeds and earth together so that the weeds cannot be burned satisfactorily.

Many State highway departments prohibit the use of blades on ditches, shoulders, and slopes, as they desire these areas to become covered with vegetation. Some States even haul in material to keep the shoulders smooth rather than use a blade. In the arid regions of such States as Arizona, New Mexico, and Nevada, and in places where firebreaks are desired, blading has been used quite extensively to remove weeds. Even in these sections there is an increasing tendency to mow the weeds and allow growth of vegetation in harmony with the surrounding country. Mowing allows the soil humus to be built up to support desirable vegetation sooner than if blading is practiced. Removing weeds with a blade pulled by a truck or tractor costs about the same per cutting as by mowing but the seasonal cost is less as blading is not required so often.

DRAGGING, HAND PULLING, AND SMOTHERING OF WEEDS USED TO A LIMITED EXTENT

Dragging.—A number of improvised drags are used by highway departments for clearing weeds from the right-of-way. In New Mexico frames of 4-by-4-inch timber 12 feet long and 7 feet wide faced with old grader blades extending three-fourths of an inch below the timbers are used in the fall to gather tumbleweeds along shoulders. The drags are pulled by light trucks and are automatically dumped when full of weeds. One man with this equipment can cut and pile the weeds on both shoulders of a highway ready for burning over an average length of 15 miles of road per day.

Pulling Dry Weeds on a Desert Road by Means of a Weighted Wire Mesh.

In South Dakota A-frames are used to clear weeds from the right-of-way, and in Wyoming cables or chains weighted with pieces of iron serve the same purpose Other States use harrows for cutting and piling the weeds.

These methods tend to spread the seeds but are effective in removing tall weeds which may cause snowdrifts, especially in the semiarid sections where the run-off from the surfaces causes an abnormal growth of weeds on the shoulders. Little damage is done to desirable grasses.

Steam.—Although a number of railroads have used steam in keeping down the weeds along their tracks, there is no record of similar practice on roadsides. The probable reason is that the railroads have equipment on hand that can readily be adapted to this purpose. Superheated steam does not actually destroy weeds and will not kill hardy or fibrous vegetation; it merely wilts the tops and keeps them down temporarily. The less hardy types are killed. A first application at 600 to 900° F. during the early growing season while the vegetation is tender, followed by a second application 3 or 4 weeks later has been found by the railroads to give the best results. Steam boxes 20 feet long are moved at 2½ miles per hour where the growth is thick and at 4 miles per hour over areas with small weeds.

The average cost per treatment including labor, materials, equipment, and overhead is reported as $10.93 per mile over 6,272 miles or approximately 1 dollar per mile per foot of width. Four treatments per year are usually required.

Hand pulling.—Hand pulling, spudding, and hoeing, although very effective methods of weed eradication, are too costly to be used to any great extent on roadsides. Their use is confined to the control of special areas or to the supplementing of mechanical methods in spots not reached by the equipment. A few scattered weeds that are very undesirable can be removed by hand with little work, whereas if allowed to mature they may thoroughly seed a larger area and make more trouble in the future.

The best time to pull or hoe weeds is while the ground is moist and while they are in full bloom, as the roots are then the weakest. This is especially true for annuals and biennials that are largely exhausted.

Smothering.—Smothering of undesirable vegetation can be done by covering with burlap, paper, or other material, to exclude the light or by planting or making conditions favorable for vegetation that will crowd out the objectionable plants by either root or top growth. The first of the two methods is impractical for large areas but has been used to a very limited extent on patches of poison ivy and other vines.

Any grass, plant, vine, or shrub that has no undesirable tendencies and is hardy enough to withstand or predominate over the weeds by making conditions unfavorable for them can be used as a smother crop. In cultivated fields, millet, Sudan grass, oats, corn, peas, and sorghum have been successfully used to reduce the number of weeds prior to planting other crops. Native perennials or annuals that will reseed themselves are more desirable for smothering weeds on roadsides. Some State highway maintenance departments favor suitable low-growing ground covers like colorful wild flowers and dwarf grasses by raising the mower blade sufficiently to permit the low-maturing plants to reseed themselves naturally, without competition from high-growing, objectionable species like Johnson grass.

Maintenance supervisors should not, however, permit attractive blooms or misleading names to prevent the early destruction of such weeds as the oxeye daisy, toad flax, Jimson weed, wild carrot, and flowering spurge if they are adjacent to cultivated fields. Common misnomers of these weeds are white daisy, wild snapdragon, devil's trumpet, Queen Anne's lace, and baby's breath, respectively. The Shasta daisy is bigger and showier and should be encouraged in place of the oxeye daisy, as it does not have the tendency to become harmful.

VARIOUS CHEMICALS USED TO KILL WEEDS

Many States cover steep slopes that are impossible or difficult to mow with appropriate woody, groundcover vegetation like native vines, Japanese honeysuckle, wild grapes, dwarf flowering locust, low forms of sumac, and even dwarf varieties of cacti. In addition to increasing the esthetic benefits, such plantings should have as their objective a reduction in maintenance expenditures. Garden shrubs placed on high

Piles of Weeds That Have Formed a Carpet Over the Edges of the Pavement. These Weeds, About 6 Months Old Have Been Cut at Intervals of 10 or 15 Feet and Rolled Up Preparatory to Removal.

banks and struggling for existence against uncut weeds are not effective and should not be planted.

The present knowledge of the use of chemicals for controlling weeds has been developed during the past 45 years, though the most progress has been made during the last 10 years. Except for a few chemicals such as arsenical compounds, salt, or oil used to kill weeds along paths, driveways, and roads, the development of their use has been primarily for agricultural purposes. Many important facts concerning the use of chemicals for weed eradication and control that have been brought out in these developments should be known by highway maintenance departments.

Numerous examples are available to show that the use of herbicides in the control of weeds along highways is both practicable and economical under certain conditions. In one political subdivision the use of chemicals on roadsides for 4 years has made it possible to reduce the expenditures for weed control to one-sixth the amount formerly spent when only cutting and mowing were practiced. Further reduction in cost is anticipated by their continued use. Several of the larger railroads favor chemical treatment in preference to repeated mowing or cultural methods which are slow and difficult to effect.

The following is a list of the most important herbicides:

Ammonia compounds.
Arsenic acid.
Carbolic acid.[1]
Carbon bisulphide.
Caustic soda.
Common salt.
Copper nitrate.
Copper sulphate.
Crude oils.
Cyanide compounds.
Formaldehyde.[1]
Hydrochloric acid.[1]
Iron sulphate.
Kerosene.
Mercuric chloride.[1]
Nitric acid.
Sodium arsenite.
Sodium chlorate.
Sodium nitrate.
Sulphuric acid.

Chemicals suitable for killing weeds along highways must be effective, easily applied, and cheap enough to be more economical for the particular work than other methods. They may be grouped into three types:

1. Chemicals that produce soil sterility for a period of several months.
2. Chemicals that kill all vegetation but do not produce sterility of the soil for any appreciable time.
3. Chemicals used in selective sprays to kill certain weeds without permanent injury to other vegetation growing among the weeds.

Some chemicals may be used to make a solution that will fall in any one of these classes by properly controlling the concentration or the rate of application.

The herbicides falling in group one may be used on the traveled way of highways, driveways, and walks, on patches of weeds, and sometimes on shoulders, along fences, under guardrails, and around culvert headwalls and route markers. Those of the second group are used chiefly on areas where it is desired to replace the present growth with more suitable vegetation. Chemicals of the third group, now used chiefly in the treatment of grain fields, might possibly be used in the treatment of lawns and grass-covered roadsides.

Table 1 lists the weeds killed, the chemicals used, the solutions or rates of application, and general information regarding effective experimental or practical applications of herbicides by various State and Federal agencies, commercial firms, and individuals as reported in publications on chemical weed control. The bibliography at the end of this report shows the source of all information presented in table 1.

Ammonium sulphate.—Although ammonium sulphate is one of the best chemicals for the control of weeds on

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[1] Use limited to experiments so far as is known.

TABLE 1.—*Summary of effective herbicidal applications*

[As obtained by review of publications on chemical weed control]

Bibliographical reference number	Authors' classification of weeds reported killed	Chemical	Rate of application			Remarks
			Pounds of chemical		Gallons of solution per 1,000 square feet	
			Per 100 gallons of water	Per 1,000 square feet		
[illegible]	Dandelions in lawns	Ammonium sulphate	125	8.4	6.7	Apply dry or in solution 3 to 5 times 2 weeks apart during early spring or late fall on cloudy, damp days while the grass is dry. Chemical acts as fertilizer to lawn grass.
52	Lawn weeds	do	50	3.0	6.0	
52	All vegetation	Ammonium thiocyanate	200	8.0	4.0	No toxic effect after 3 months when sulphur is added to the soil. Converted into ammonium sulphate, which is a good source of nitrogen for plants. Best results if applied in solution.
29	Deep rooted weeds	do		22.0		
29	Canada thistle, poison ivy, quack grass, and sow thistle	do		14.7		
22	All vegetation	Copper sulphate	20–30	0.28–.42	1.4	Use spray in clear weather.
52	Wild mustard and radish	do	[1] 25			Saturate plants. Used as selective spray for grains.
22	All but grass and grains	Iron sulphate	200			Spray while plants are growing, on clear, bright day
[illegible]	Buttercup, chickweed, dandelion, heal all.	do	150	5.0	3.3	Use on warm, dry days. Injures clover but not grass.
17	Dandelions in lawns	do	150–200	4.4–5.8	2.9	Spray 4 or 5 times 1 month apart.
37	do	do	125	8.4	6.7	Apply 3 to 5 times 2 weeks apart in spring when grass is dry, on cloudy, damp days. Will not hurt lawn. Mow lawn before applying.
38	Dandelions	do	150	4.5	3.0	
52	Dandelions in lawns	do	200	5.0	2.5	
17	Moss in lawns	do	125	1.4	1.1	
11	Annual weeds	Arsenic acid	8.4			
49	Hard-fern	Arsenic pentoxide	3			Spray during December to April.
49	Hoary cress	Arsenite	50	2.2	4.4	Spray during warm, dry weather
24	All vegetation	Arsenic trioxide		6.9		Spray, adding 4 pounds soap per 100 gallons of solution.
24	Wild morning glory	do	4			Roots killed best in fall. Spray during moist weather.
52	Bindweed	Arsenite Sulphuric acid	1 5	.12 .6	11.5	Mix chemicals in quantities indicated.
52	Shrubs	Arsenite	10			2 to 4 gallons per shrub, depending on size.
63	All weeds—average conditions	Sodium arsenite	10	1.4	13.8	2 or 3 applications for perennials, 1 application for annuals.
63	All weeds—in Idaho	do	3.3–4.2	.45–.58	13.8	
22	Most weeds	Caustic soda White arsenic	4 8	.46 .92	11.5	Large vegetation should be mowed before spraying. Mix chemicals in quantities indicated.
1	All weeds	Caustic soda White arsenic	5–6 18–20			Mix chemicals in quantities indicated.
30	Canada thistle, quack grass, and wild morning glory	Caustic soda White arsenic Sulphuric acid	1.1 4.4 5.6			Caustic soda and white arsenic are mixed in concentrated solution and added to water with sulphuric acid as needed. Apply as spray when plants are dry and wilted but when air is moist.
52	Lawn weeds	Lead arsenate		5.0		Apply dry. Results are not certain.
52	All types	Carbon bisulphide				Apply at roots.
[illegible]	Perennials	Carbon disulphide				Apply in holes 2 feet apart. Make holes 12 to 18 inches deep.
63	All; especially grasses	Oil		[2] 6.9		Kills seed.
11	Annual weeds and seeds	Diesel oil		[2] 6.9		
[illegible]	Roadside vegetation	do		[2] 11.1		Used to provide firebreak in California.
22	All vegetation	Petroleum oil		[2] 6.9–9.2		
52	Annual weeds	Sulphuric acid	25–84	.6–1.2	1.4–2.9	Spray when atmosphere is dry.
34	Most weeds	do	17–84			(Experiments in Arizona).
34	Puncture vine	do	17			Do.
10	Wild mustard	do	84	2.5	3.0	For use during normal weather.
10	do	do	125	2.6	2.1	For use during damp days.
30	Canada thistle, morning glory, poverty weed, quack grass, etc.	Calcium chlorate or magnesium chlorate.		11.0		(Experiments in Idaho). Use 18.4 pounds per 1,000 square feet in irrigated soil.
30	Blue flowering lettuce, sow thistle, white top.	do		22.0		(Experiments in Idaho). Use 29.4 pounds per 1,000 square feet in irrigated soil.
30	Yellow toad flax	do		14.7		(Experiments in Idaho).
30	Leafy spurge	do		25.7		Do.
[illegible]	Canada thistle	Potassium chlorate	54			
[illegible]	do	do		5.5		Apply dry in late fall.
1, 5, 30, 39, 50, 60, 63, and 67.	Common perennials	Sodium chlorate	100			
[illegible]	Annuals and biennials	do	100	5.0	5.0	
5	Perennial weeds	do		7.4		Apply dry when tops are dead.
62	Perennials	do	150	7.5	5.0	
[illegible] and 56.	Most weeds	do		11.0		Use dry or in solution during cool weather.
28	Most vegetation	do	200	7.4	3.7	One application only at blossom time.
28	Most vegetation including bindweed and perennials.	do	100	2.3	2.3	First application at blossom time, rest after new growth starts, 2 or 3 applications necessary.
62	Arkansas bedstraw, cypress spurge, leafy spurge and St. John's wort.	do	150		Saturate	Spray when 4 to 5 inches high and repeat in a month's time.
53	Bermuda grass	do		4.6		Two applications necessary in Oklahoma.
[illegible]	Bindweed	do	100-150		Saturate	Spray during flowering stage or late June and repeat in a month's time.
[illegible]	Bindweed: Heavy growth Ordinary growth	do do	100 100	3.4 2.3	3.4 2.3	Apply on moist days. Soil not sterile long.
[illegible]	Bindweed: First treatment Second and third treatments	do do	100 100	3.4 2.3	3.4 2.3	3 treatments. First treatment before plants bloom.
37	Bindweed	do	100-300	9.2–11.0		Soil conditions govern solution to be used.
40	Bindweed: First treatment Second and third treatments	do do	100 100	3.4 2.3	3.4 2.3	2 or 3 treatments necessary when weeds are in full bloom.
1	Bindweed: First treatment Second treatment	do do	100 100	4.6 2.3	4.6 2.3	First treatment latter part of June when there is a heavy growth. Second treatment 6 weeks later.[3]
30	Bindweed, Canada thistle and quack grass.	do	100	11.0	11.0	Experiments in irrigated sections of Idaho.

[1] Amount for dry regions. In moist climates use 42 pounds of copper sulphate per 100 gallons of water.

[2] Gallons.

[3] One-half teaspoon of sulphuric acid and 1 teaspoonful animal glue to each gallon makes solution more effective. Acid hastens diffusion through cuticle. Glue keeps foliage in contact with the weed longer.

TABLE 1.—*Summary of [illegible] herbicidal applications*—Continued

Bibliographical reference number	Authors' classification of weeds reported killed	Chemical	Rate of application			Remarks
			Pounds of chemical		Gallons of solution per 1,000 square feet	
			Per 100 gallons of water	Per 1,000 square feet		
30	Blue flowering lettuce, leafy spurge, perennial sow thistle, white top.	Sodium chlorate	100	18.4	18.4	(In Idaho). In irrigated sections use 22 pounds per 1,000 square feet.
30	Canada thistle, morning glory, poverty weed, quack grass, and Russian knapweed.	do	100	7.3	7.3	(In Idaho). In irrigated sections use 14.7 pounds per 1,000 square feet.
62	Brush	do	125-150			Spray young shoots in spring after cutting during winter.
11	Canada thistle	do		[illegible]		Apply dry during fall. (Experiments in New York)
19	Canada thistle:					
	First treatment	do	150			
	Second treatment	do	250			
51	Canada thistle	do		[illegible]		Apply dry in late fall.
41	Canada thistle, European bindweed, Johnson grass, quack grass, sow thistle.	do	[1] 100			Respray in 6 weeks.
52	Chickweed, growing ivy, speedwell, and other broad-leaved, shallow rooted weeds.	do	9.4	.94	10.0	Will not injure grass. Kills crabgrass seedlings.
3	Chickweed, ground ivy, ironweed, oxeye daisy, speedwell, poison ivy.	do	12.5	1.25	10.0	Apply during cool weather. Does not injure grass.
62	Goldenrod	do	100			
26	Johnson grass	do		2.3		2 treatments required in Oklahoma.
5 and 51	Leafy spurge	do		7.3		Apply dry in late fall. (Experiments in New York.)
66	Oxeye daisy	do	50			No injury to grass during July. (Experiments in Ohio.)
62	Perennial sow thistle	do	100			Spray thoroughly and repeat in a month.
17	Poison ivy	do	100			Soak soil. 2 or 3 treatments may be needed.
28	do	do	200	7.4	3.7	1 application usually sufficient.
62	do	do	100			Saturate plants. 1 spraying usually effects 100 percent kill.
5	Quack grass	do		7.4		Apply dry in fall.
19 and 60	do	do	100	11.0	[illegible]	(Experiments in Washington and New Jersey.)
58	do	do		5.7		2 applications necessary (experiments in Virginia.)
66 and 67	Quack grass and Canada thistle	do	100	7.3	7.3	Total of all treatments 17.7 to 18.4 pounds per 1,000 square feet.
62	Ragweed	do	50- 75			Spray just before coming into blossom.
54	Rifes petrolare	do	42- 84			
22	All vegetation	Sodium chloride [3]	300	3.3-24.0	1.1-8.0	92 to 459 pounds per 1,000 square feet if applied dry. Apply on hot dry days. Removes all growth for a season.
52	Barberrybush, dandelions, poison ivy, and poison sumac.	do	300			Spray thoroughly. First application when leaves are full grown. Second and third as new leaves appear.
16 and 37	Bindweed	do		1,000		Almost permanent detrimental effect on soil.
68	do	do		918		Very expensive
63	Most vegetation	do		1,000		5 to 10 tons per acre on large areas.
17	Poison ivy	(3)	300			Soak soil. Repeat in 2 weeks if necessary.
28	do	Sodium chloride [4]		1,000		Place ½ inch thick on ground.

[1] Quantity for large plants. Use 150 pounds per 100 gallons of water as a respray.

[3] Common salt.

[4] Rock salt.

lawns, it is too expensive to be used to any great extent on roadsides. Traffic circles, center islands, parkings, and landscaped areas where the grass is kept mowed short and a dense turf is desired may be benefited by the use of ammonium sulphate. It is not only harmful to dandelions and many other common lawn weeds but also acts as a fertilizer to the grass. However, repeated use tends to make an over-acid soil that may be detrimental to the grass. The lawn should be well watered not sooner than 24 hours and not later than 48 hours after each treatment to prevent the grass from being burned.

Ammonium thiocyanate.—Ammonium thiocyanate, a byproduct of coke plants, acts on all vegetation very rapidly, but does not sterilize the soil for more than a few weeks. It is highly soluble, noninflammable, absorbs moisture from the air, and decomposes in a few weeks, liberating desirable fertilizers. These features, together with the fact that stock will not eat sprayed vegetation because of its repellent taste, make it a desirable herbicide for treating small areas of vegetation. Its cost—17 to 20 cents per pound during 1935—prohibits its use on large areas.

Copper sulphate.—Copper sulphate solution is sometimes used as a selective spray for killing young weeds, especially those such as wild mustard and wild radish plants, in localities where iron sulphate and sulphuric acid are not readily available. For best results, it should be used while the plants are still young and tender. It should be applied as a fine spray on clear days when there will be no rain for several hours.

Iron sulphate.—Iron sulphate has much the same destructive effect on dandelions and broad-leafed lawn weeds as copper sulphate and is a little lower in price. Grasses and grains are very resistant to the spray, and although it slightly blackens them at first they will soon recover.

Iron sulphate can be applied dry or in solution. A fine spray applied on humid days when rain is not likely to fall soon is most effective. Small patches can be sprayed with a sprinkling can or the chemical can be applied dry. If rain falls soon after spraying, the chemical will be washed off before the weeds are damaged. When application is made in dry weather the solution will dry and the residue falls off of the leaves before they are affected. The first application should be made in early spring and the other three to six necessary applications at intervals of 10 days to 2 weeks. Spraying should not be done in midsummer when the grass is inactive and the soil very dry. Lawns should be mowed 2 or 3 days both before and after spraying. Undesirable stains are produced when the solution comes in contact with buildings, walks, or clothing.

A, Firebreak Strip Formed by Treating Vegetation With Sodium Chlorate. B, Appearance During the Summer of Area Around Guardrail Where Sodium Chlorate Was Sprayed the Previous Fall.

SPECIAL CARE NECESSARY IN USE OF CHEMICALS THAT ARE POISONOUS TO MAN OR ANIMALS

Arsenicals.—Arsenicals have been used extensively as contact sprays for killing weeds along railroad tracks, highways, and, to some extent, in fields. Many commerical weed-killing solutions contain sodium arsenite.

The principal objection to arsenic and all its compounds is that they are very poisonous to both man and beast. When sprayed upon weeds they give them a brackish, sweet taste that is attractive to grazing animals. The greatest care must be exercised not to inhale the dust or fumes or to bring the hands near the face or mouth while using this chemical. Arsenicals should not be used near playgrounds or where they can be reached by children or animals. Utensils used in preparing them should always be thoroughly washed and should never be used for cooking purposes. Vegetation deadened by arsenic compounds should be burned.

A few years ago the use of arsenic sprays was replaced to a great extent by sodium chlorate solutions to eliminate the danger of poisoning livestock. Sodium chlorate solutions are several times as expensive as arsenic solutions and there is always the danger of fire. During the last year or two arsenicals have come back into more general use because of the development at the University of California of an acid arsenical solution and improved knowledge of its use.

The method of preparing and applying the acid arsenical solution as given by L. W. Kephart, senior agronomist of the United States Department of Agriculture, is becoming standard practice because of the low cost and the relatively high efficiency in killing very troublesome perennial weeds. This method is as follows:

Stir the following solution until dissolved—

White arsenic	4 parts by weight.
Caustic soda	1 part by weight.
Water	$2\frac{1}{2}$ parts by weight.

When required for use add 1 part by weight of the solution to 100 parts of water. After mixing thoroughly, add 5 parts by weight of a commercial grade of sulphuric acid slowly while stirring constantly.

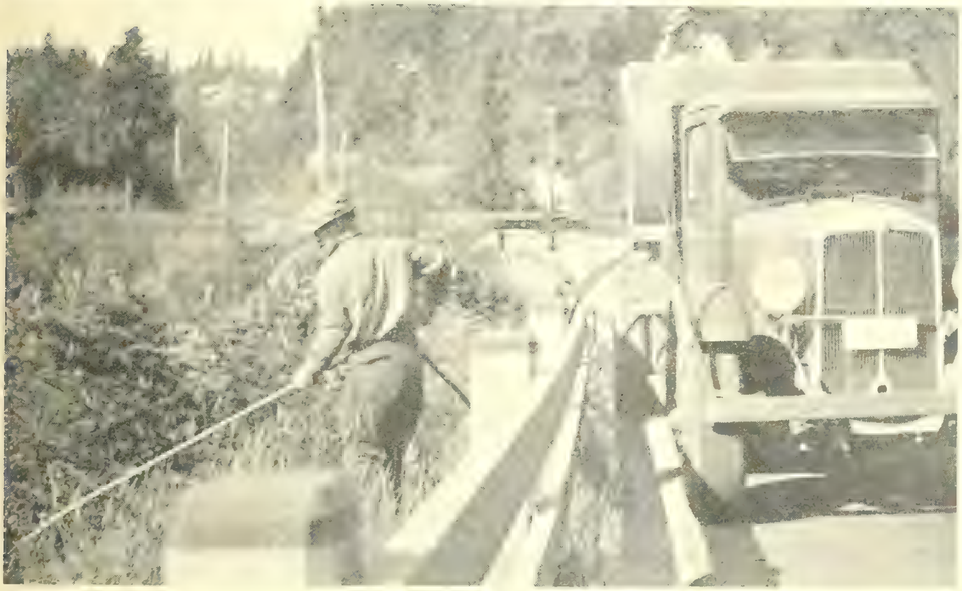
It is highly important that the plant be in proper condition to take the chemical into its tissues when the spray is used. This condition occurs when the plants are wilted after hot, dry weather, but when the atmosphere is moist so that evaporation is not high. Under such conditions, a solution sprayed on the foliage is taken up by the leaf tissues and drawn downward into the stem by reason of the negative pressure within the plant cells. The acid in the solution makes the leaf surfaces more permeable. Broad-leafed weeds are affected to a greater extent than grasses.

Slopes Covered With Desirable Vegetation Make the Roadsides Attractive and Reduce Maintenance Costs.

In practice it has been found that the best kill is obtained when full-grown plants are sprayed towards night after a few hot, dry days. Several authorities recommend the addition of 3 or 4 pounds of soap to each 100 gallons of solution for waxy-coated foliage where the spray has a tendency to collect in drops.

While arsenic makes soil very toxic when applied in large quantities, as in the root-absorption method, the amount required for the leaf-absorption method is so small that no ill effects to the soil can be detected after several applications. It is the cheapest and most effective herbicide to use when permanent sterilization is desired on areas where there is no danger of poisoning people or livestock.

Applying Chemical Weed Killer



Truck equipped with U-Shaped Device for Spraying Around Posts and Under Rail. Weeds Behind Rail Are Being Sprayed Using a Pipe Attachment.

Applying Chemicals to Kill Weeds.

Carbon bisulphide.—The use of carbon bisulphide as an herbicide has been limited by the cost, especially the labor cost, and the danger of handling this inflammable and explosive chemical. The present method of application by making a large number of holes in the soil, pouring a small quantity of the chemical into each, and capping with earth is practical only for small areas of weeds when large regions of weed-free land are in danger of being invaded.

Complete killing of perennial weeds, for which this chemical has been chiefly advocated, depends upon favorable conditions which as yet are not fully understood. The depth of the holes, the distance between them, the amount of liquid used, and the porosity of the soil are variable factors that affect the results obtained. Dense soils do not allow the distribution of the liquid and gases that is necessary to kill the roots.

CORROSIVE EFFECT OF CHEMICALS ON EQUIPMENT MUST BE CONSIDERED

Sulphuric acid.—Sulphuric acid in dilute solutions has been used quite extensively as an herbicide in Europe, especially France, where its use has been most energetically carried on for a number of years. Owing to the difficulties of handling this highly corrosive chemical which burns clothing and flesh, it has rarely been recommended in the United States although it is entirely safe if handled with reasonable care.

Sulphuric acid is a very active and efficient herbicide as a spray for killing annual weeds. It is not effective on grasses or perennials with extensive root systems unless several applications are made. Other advantages of using sulphuric acid on roadsides are that it is not poisonous to animal life, does not injure the soil, and is one of the most inexpensive herbicides.

Dilute solutions of sulphuric acid may be applied under all conditions of humidity, but best results have been obtained in a dry atmosphere and in hot weather. Dilute solutions are, therefore, very useful in the more arid regions where other sprays are not so effective. They do not dry up, and destroy weeds in a short time. Rain falling 2 or 3 hours after the sulphuric acid spray has been applied does not destroy its effectiveness.

The necessary concentration of the solution depends not only on the species but also on the age and size of the weeds and on the temperature. Usual practice is to spray the foliage with a 3 to 10 percent solution at the rate of 50 to 100 gallons per acre. The solution does not affect the germination of seeds and it is most effective when applied to young plants so as to kill them before they form seed.

The use of sulphuric acid as an herbicide has been retarded largely by lack of sprayers that will resist corrosion. Standard types of spraying equipment are quickly damaged by sulphuric acid solutions. The concentrated acid will not attack steel but is very destructive to rubber hose. Dilute solutions, on the other hand, will corrode steel and wrought iron but will not affect rubber. Standard spraying outfits may be readily converted into satisfactory equipment for applying acid solution by injecting the concentrated acid contained in steel drums directly into the rubber spray line by means of a simple venturi tube. Special injectors of suitable sizes similar to a venturi tube are obtainable from plumbing dealers. Recently, the venturi-tube method has been replaced to a large extent by the acid pump method. The latter does not require as high a pressure.

The cost of sulphuric acid during 1935 was approximately $1.40 per 100 pounds when bought in 100-gallon lots. Using a 10 percent solution or 6.05 gallons of concentrated acid per acre, the acid costs $1.50 per acre. The labor and equipment for spraying and the cost of hauling water are usually about $1.50 per acre, making the total cost around $3 per acre. This figure may be reduced or increased depending on the distance water must be hauled and the rate at which the solution is applied.

Chlorates.—Chlorates of calcium, magnesium, potassium, and sodium have been used successfully as herbicides. At the present time sodium chlorate or commercial compounds or other mixtures containing sodium chlorate are probably the most widely used herbicides. Oils and chlorates are practically the only herbicides now being used by State maintenance departments on roadsides. Sodium chlorate is not a magic weed destroyer; it has its limitations. Like most herbicides, it affects all vegetation, so it cannot be used as a selective spray except in rare instances when a thorough knowledge of the amount required to kill each type of vegetation is known.

The chief objection to sodium chlorate is the fire hazard associated with its use. The chemical in itself is not dangerous, inflammable, or explosive, but a mixture of it with organic matter is even more dangerous than gasoline, since it can be ignited by friction, sparks, shock, or spontaneous combustion under favorable weather conditions. Solutions in containers or on clothing and vegetation are not inflammable while wet but, unfortunately, they dry rapidly, causing fire hazards.

Experiments by Dr. W. H. Cook of the National Research Council, Ottawa, Canada, indicate that at relative humidities above 75 percent materials treated with sodium chlorate solutions are noninflammable because of the moisture content always present. The moisture content decreases rapidly at relative humidities slightly below 75 percent, making inflammable any treated organic material.

Experiments and practical applications have definitely shown that sodium chlorate solutions are not as effective in arid regions where humidity is low as in moist climates. In arid regions the leaves do not have sufficient time to absorb the solution before it dries. A practical criterion to follow is that the solutions will not be effective in killing weeds unless applied during periods when dew forms on the vegetation at night.

RELATIVE HUMIDITY IMPORTANT CONSIDERATION WHEN SODIUM CHLORATE SOLUTIONS ARE USED

One method of reducing the fire risk is to mix sodium chlorate solution with chemicals of high water-absorbing ability such as calcium chloride or with other nonoxidizing chemicals of good herbicidal power, the latter acting as a diluent and fire preventative when in contact with organic material. Calcium chloride and sodium carbonate are the two substances most commonly used with sodium chlorate in commercial herbicides. The chief function of the calcium salt is to reduce the fire hazard by absorbing moisture from the air although the claim is made that it improves the herbicide by preventing the solution from drying on the leaves and blowing off. The reason for using sodium carbonate is not definitely known, but it may retard the spreading of flames by the evolution of carbon dioxide or increase the herbicidal power of the chlorate.

Dr. W. H. Cook recommends the following herbicides as being safe at relative humidities of 40 percent and no more than doubtful hazards at 30 percent relative humidity. Proportions of all chemicals are on an anhydrous basis.

1. One-half sodium chlorate plus one-half calcium chloride.
2. Two-thirds sodium chlorate plus one-third magnesium chloride.
3. Two-thirds barium chlorate plus one-third calcium chloride.
4. Two-thirds barium chlorate plus one-third magnesium chloride.

The toxicities of these four mixtures expressed as percentages of the toxicity of pure sodium chlorate as determined by the chlorate ion content of the hydrated material are 33.5, 48.3, 34.2, and 32.9 percent, respectively. To obtain solutions with the same herbicidal power that sodium chlorate alone has, the total amount of chemical per 100 gallons of solution must be approximately doubled if the second combination is used and tripled when the others are used.

Before attempting to use sodium chlorate solutions it is well to consider the relative humidity at the time and place that application is to be made. This will help to reduce both the fire hazard and chances of unfavorable results.

Figure 1, prepared from data furnished by the United States Weather Bureau, illustrates the variation throughout the United States in the average minimum relative humidity during the month of July over a period of years. The chart may also be considered as being typical for the months of June through September. More important than average relative humidity is the frequency with which the humidity falls below certain minimum values. Data were obtained by determining from Weather Bureau reports the number of days each month that the relative humidity fell below 30 percent during the 4 months of June through September for the years 1930, 1931, 1932, and 1933 at 34 typical stations throughout the United States. These data are shown as circled figures on figure 1.

There is no portion of the United States where the use of sodium chlorate would not constitute a fire hazard at the period of minimum relative humidity during

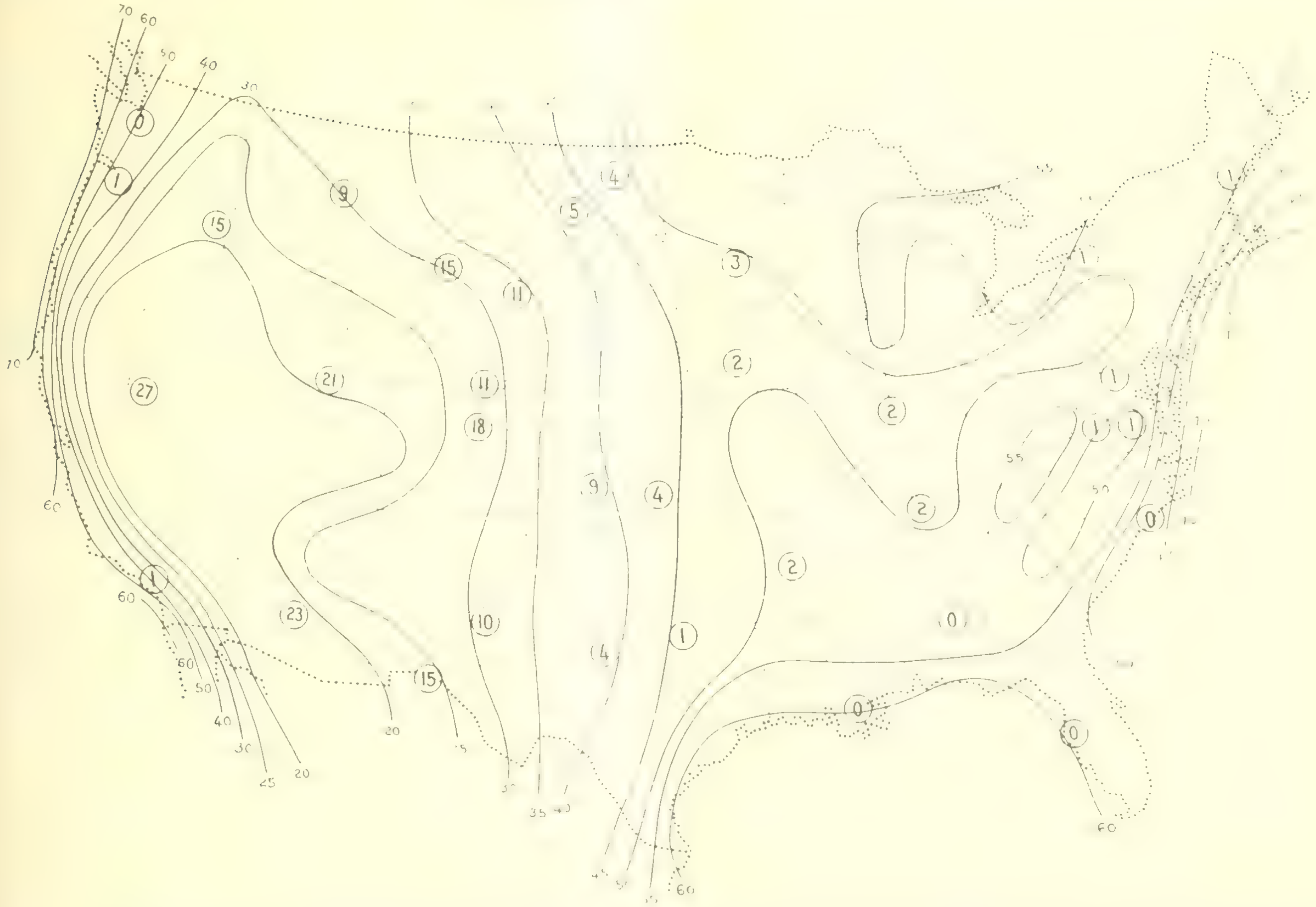


Figure 1.—Average Relative Humidity for July. Circled Figures Show the Average Number of Days per Month That the Relative Humidity Went Below 30 Percent During June, July, August, and September From 1930 Through 1933.

the majority of days from June through September. Even with a protecting agent that reduces the herbicide to a doubtful hazard at 30 percent relative humidity, it could not be considered safe if applied on roadsides in the western and midwestern States, as the relative humidity frequently falls below 30 percent. A chlorate herbicide safe at relative humidities below 30 percent requires such a large portion of protecting chemical that its use is impracticable owing to the cost and loss of herbicidal power.

The absolute amount of moisture in the air or the vapor pressure usually varies only slightly in a given locality during any one day. The relative humidity varies almost inversely as the temperature—being highest at low temperatures and lowest at high temperatures. This is illustrated by figure 2, which shows the hourly changes of temperature and relative humidity in four cities located in various parts of the country.

The temperature usually reaches a maximum for the day between 1 and 5 o'clock in the afternoon at most locations throughout the United States. This is therefore the most hazardous time of the day to apply chlorate solutions. As a general rule, the relative humidity is also lowest on warm days. The preferable time to apply sodium chlorate solutions is therefore on cool, humid days. The same precautions should be taken with commercial herbicides containing sodium chlorate, as the majority produce distinct fire hazards at low relative humidities although manufacturers rightfully claim that the danger is greatly reduced.

SODIUM CHLORATE CAN BE APPLIED DRY OR IN SOLUTION

The following precautions should be taken by the operators using solutions of sodium chlorate:

1. While spraying, use rubber boots. Clothes saturated with the solution should be well rinsed before they dry.
2. After using pails or other utensils, wash them out thoroughly before setting them away.
3. Trucks, wagons, and other equipment being used should be washed off 2 or 3 times a day, particularly in warm weather.
4. Do not smoke while handling chlorates.
5. Warn the public as to the danger of walking through treated areas by placing "KEEP OFF" notices. After 2 or 3 rains have fallen most of the fire hazard will have been eliminated.

Best results are usually obtained by application while the foliage is fully developed and the plants are still growing vigorously. Sprayed plants should not be burned or cut immediately after the solution has been applied. Burning destroys the chlorate and cutting prevents the roots from being poisoned.

It is impossible to determine in advance just how much chlorate will be required. The amount varies with climate, soil fertility, root growth, and soil texture. A fibrous rooted annual or biennial requires less chemical than a perennial with a deep, underground root stock. It is general practice to spray a solution containing 1 pound of sodium chlorate per gallon until the leaves are well covered. This requires from 100 to

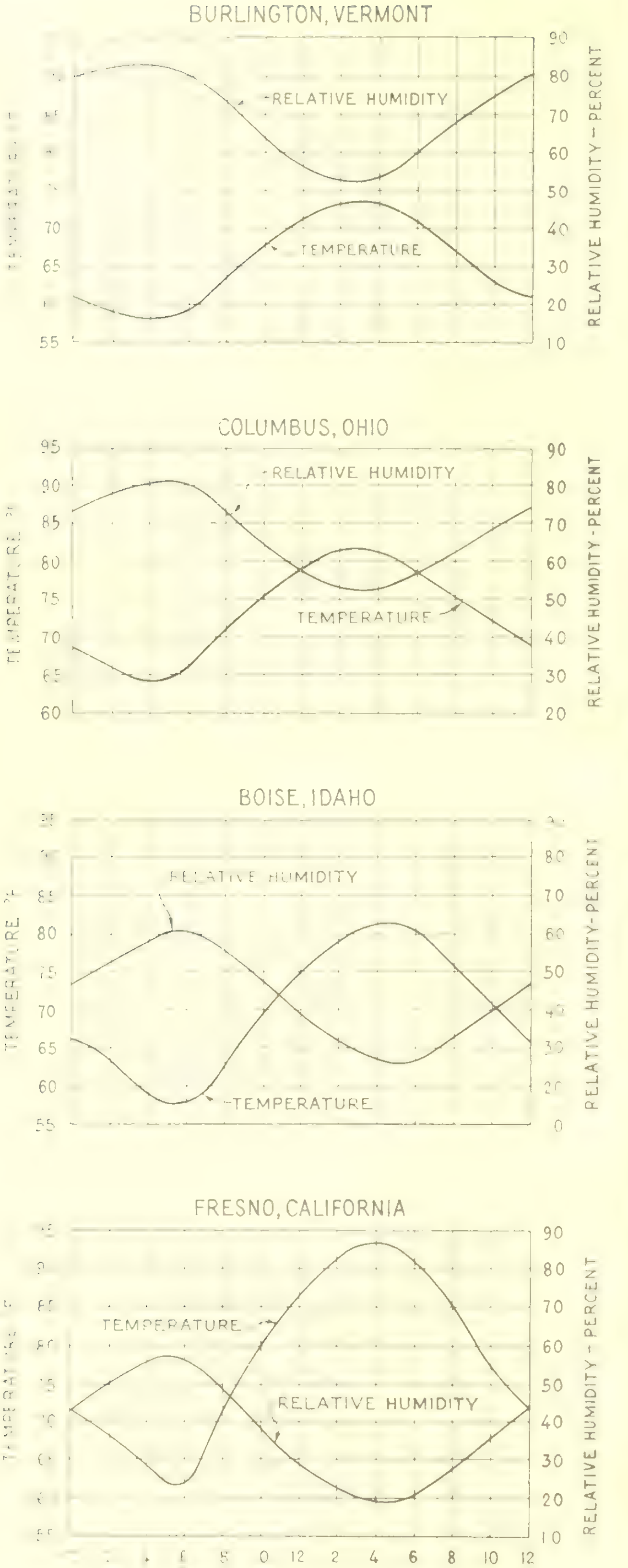


Figure 2.—Typical Hourly Changes in Temperature and Relative Humidity During Summer Months.

200 gallons of solution per acre. High-pressure spray guns ejecting a fan-shaped, mist-like spray, are the preferable means of application although for small areas sprinkling cans may be used.

The present tendency in the use of sodium chlorate is toward dry applications. Though most results indicate that sprays are somewhat more effective, they are always much more erratic than the dry applications. Applying pure sodium chlorate on the ground after removing the mowed weeds would be safe almost anywhere. Besides eliminating the fire hazard, other advantages of this method are: (1) No spraying equipment is required; (2) it is not necessary to prepare a solution or transport large quantities of water; (3) the cost of application is reduced; and (4) only one application is usually required. The principal drawback to dry applications at present is the lack of good distributing equipment for large areas. Chlorate either dry or as a spray has been ineffective on alkali soils. The character of the soil is an important consideration, especially for dry applications. Better results have been obtained on soils of medium texture than on sandy or heavy clay soils.

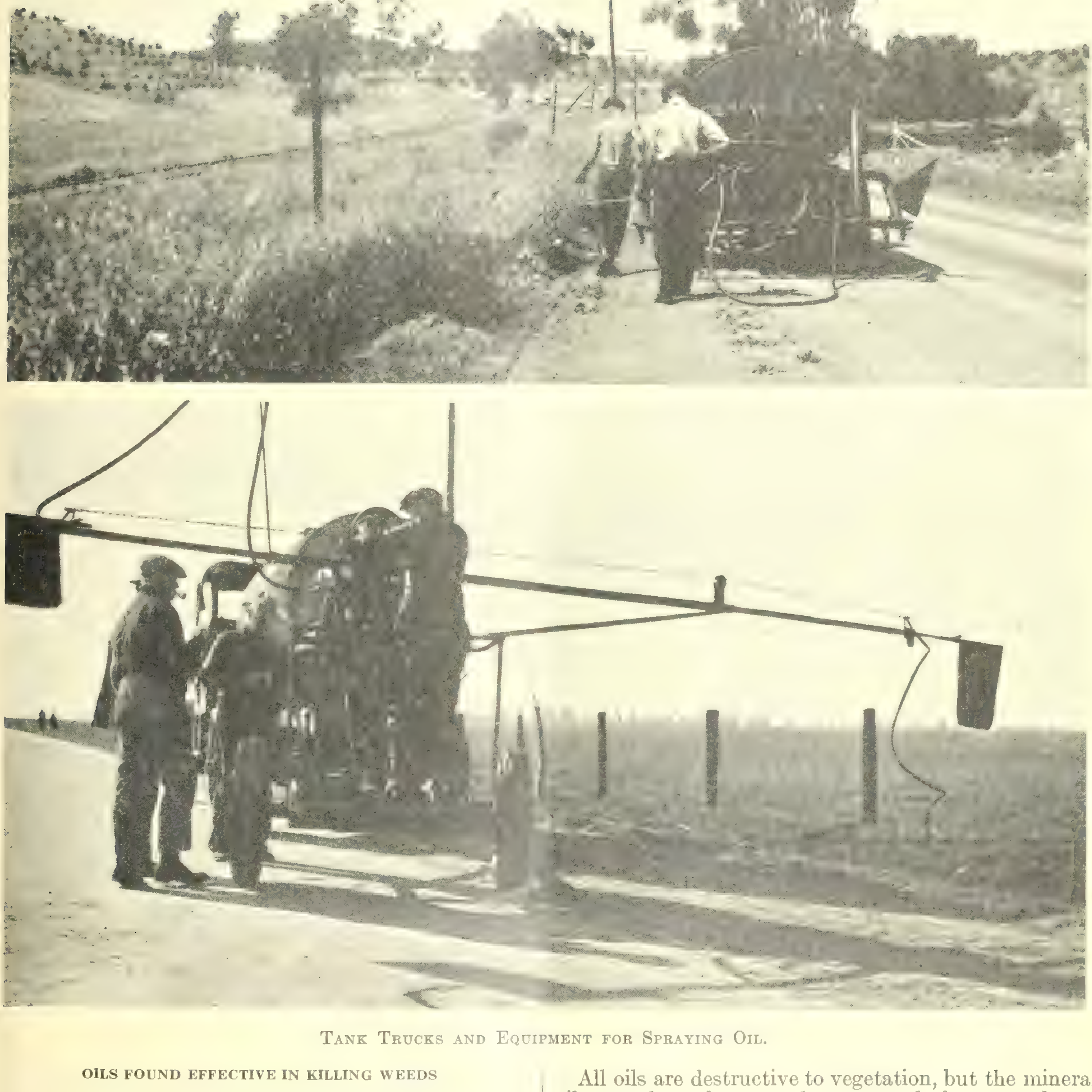
The present cost of sodium chlorate varies from 6 to 9 cents per pound. One railroad applied 21,850 pounds at a total cost of 14.4 cents per pound, including material, labor, and equipment charges.

Sodium chlorate or compounds containing this chemical have been tried for the eradication of weeds by only a few State maintenance departments. Most of the applications have been made as experiments during the last year or two so the results, although generally quite satisfactory, are not conclusive. Some maintenance departments have become discouraged and discontinued the use of this chemical.

In a maintenance district in the State of Washington sodium chlorate has been used for the past 2 years on weeds under and around guardrails with very good results. The cost was only half the cost of cutting weeds by hand, and a very neat appearance was obtained. The solution used was 1 pound of chemical to a gallon of water applied with a U-shaped spray bar for straddling the guardrail and attached to a pressure pump on a tank truck. The total cost was one-half cent per lineal foot on a strip approximately 2 feet wide. Good results were also obtained on patches of weeds along the right-of-way.

A Canadian investigator found that weeds could be completely killed on a strip 25 feet wide at a cost of \$4 to \$6 per mile. Bindweed was also completely eradicated for \$20 per acre where it was growing in sod. The investigator believes that the cost of weed control on the treated areas will be negligible as compared to the amounts now being expended for weed cutting and more satisfactory results together with cleaner roadsides will be evidenced. In Ontario, Canada, where the experiments were made, climatic conditions are generally more favorable for the use of sodium chlorate than in most sections of the United States.

Sodium chloride.—Common salt will kill weeds when applied at the rate of 1 pound per square foot. The large amount required and its permanently detrimental effect on the soil and surrounding vegetation where the salt may be washed make it impractical for roadside use except where there is no objection to rendering the soil unfit for plant growth. The Utah Road Commission has found that in certain districts common crushed rock salt was less expensive and equally as effective as any other chemical treatment.



Tank Trucks and Equipment for Spraying Oil.

OILS FOUND EFFECTIVE IN KILLING WEEDS

Oils.—Oils are effective in controlling all types of annual weeds and preventing biennials and perennials from seeding. Oils have great penetrating power and are the only herbicide that will destroy the viability of seeds. For this reason they have been widely utilized in puncture vine control. Oils are top killers and when applied as a spray do not ordinarily penetrate underground tissue.

All oils are destructive to vegetation, but the mineral oils are the only ones cheap enough for general use. Coal-tar creosote oils sometimes sold as "crude carbolic acid" are excellent weed killers for small areas but are too expensive for large-scale operations. The most promising of the oils tested for weed control are those least refined, such as crude oil, waste cylinder oil, slop distilate, Diesel oil, and stovepipe oil. Stovepipe oil is a local name for a byproduct at certain western oil refineries. The two most widely used products are Diesel oil and stovepipe oil. One is probably as efficient as the other for destroying vegetative growth, but if an emulsion is desired to reduce the cost for large-scale treatments only Diesel oil in the commercial state will give satisfactory results.

Usually oils are applied at the rate of 300 to 400 gallons per acre—a quantity sufficient to cover the vegetation and soil with a thin film. A spray pump providing a pressure above 80 pounds is recommended. Rubber parts of the spray outfit, readily attacked by oil, should be replaced by metal wherever possible.

Diesel oil is an effective herbicide for destroying vegetation in ditches, fences, firebreaks, roadsides, or similar locations. It also aids in burning vegetation.

A few authorities recommend Diesel oil as a selective spray for controlling crab grass in lawns. The danger of injuring the bluegrass is, however, very great even under favorable conditions.

Heavy applications of oil on roads and railroads act in the dual capacity of weed killers and dust layers. The amount required when acting as a weed killer alone is obviously much less than that needed as a dust preventative unless permanent sterilization is desired.

A great many State highway departments eradicate weeds with oil as an incident in stabilizing or preventing dust on shoulders and roadway surfaces. California probably exceeds all other States in its use for the sole purpose of weed eradication for fire protection. Since 1929 oil applications have been a regular part of the highway commission's maintenance program with an annual expenditure of about $80,000 on about 1,100 miles of the State highway system. The roadsides are sprayed and burned to provide a firebreak between the highway and adjoining property as well as to prevent erosion damage by protecting the natural cover from uncontrolled fires. Generally no spraying is done opposite locations where an effective natural or artificial firebreak exists adjacent to or within a reasonable distance of the right-of-way. Spraying is considered unnecessary for fire control adjacent to orchards, vineyards, plowed land, railroads, streams, or bare cut slopes 5 feet or more in height which parallel the highway, as reasonable protection already exists.

The material applied, equipment used, and methods followed in California were adopted after considerable experimentation. The most effective nonpoisonous material was found to be Diesel oil having the following specifications:

Specific gravity (A. P. I.) at 60° F.—not less than 27° Baumé.

Flash point (Penskey-Martin closed cup)—not less than 150° F.

Viscosity (Saybolt Univ.) 100° F.—not over 50 seconds.

Distillation (90 percent point)—not over 680° F.

Water and sediment—not more than a trace.

The Diesel oil is applied at an average rate of one-tenth gallon per square yard by a tank truck equipped with a pressure pump and orchard-type nozzles on a spray bar that can be raised or lowered and extended to varying distances from the truck.

For most effective and economical results the oil is sprayed on a strip 9 feet wide adjacent to the fence line when the vegetation is about 2 inches high. At this time the area is uniformly covered, practically a perfect kill of the tender growth is assured, and no burning is required. This treatment also permits burning of the section between the shoulder and sprayed area at a later date, if desired.

The chief objections to using oils are the appearance of the treated areas and the cost. Accidents have been reported by drivers who at night have mistaken the dark surfaces of treated areas for portions of the roadway or shoulders. In California the spraying cost averages from $50 to $60 per mile of highway when two 9-foot strips are treated. An additional cost of $20 per mile is incurred when burning is required. The initial cost of fire protection by blading, disking, or mowing averages about $6 per mile for a reasonable width but the ultimate cost, considering all factors involved, may well exceed the cost of spraying.

In one maintenance division of the State of Washington fuel oil and used crankcase oil were applied under guardrails with good results. The total cost was 3 cents per square foot and compared favorably with the cost of hand cutting. There was the added advantage that the treatment was good for the entire season whereas cutting was only effective for 1 or 2 months.

Another division found kerosene very effective in eliminating a dense growth of blackberry bushes that obstructed vision. They were very difficult to cut or burn prior to being sprayed but were completely eradicated by spraying with kerosene and burning 2 weeks later.

SUMMARY

Marked progress has been made in the control of weeds on our highways. Each year weeds are cut or killed by various treatments along a large mileage of road but the work is still in the transition stage. There is already available a variety of methods most of which are suitable for control work in any part of the United States. Improvements will undoubtedly be made in the existing methods and new ones will be discovered but effective control is now possible with the weapons already at hand.

The most important recommendation to be made at this time is that all work be done as part of a permanent control policy with particular emphasis on the prevention of new weed growth. Cutting weeds or killing them by other methods should not be regarded as a job to be done at some convenient time to remove unsightly objects but as a job that must be done at such times as will prevent reproduction. The major part of the problem is to prevent reseeding but some special attention must be given weeds that propagate from root growth.

Elimination of reproduction is important not only because it will make possible diminishing expenditures for control but because it is the only method by which the highways can be given the appearance of being well kept at all times.

Machine mowing is the most generally used method of weed control. In general, the costs per acre by this method are lower than by other methods. However, machine mowing is not a complete method in itself and must be supplemented by methods that are effective at places not reached by the mower. It is important that effective work in mowing not be vitiated by seed from places not reached by the machine.

Modern cross-section design with slopes that can be reached by a mowing machine and side ditches that can be mowed over greatly increase the effectiveness of machine mowing.

Burning is practiced largely to dispose of cut or killed weeds. Oil and sodium chlorate are the materials that have been applied most often as weed killers in highway work, and are effective. They are useful for general applications, as supplements to mowing and to kill weeds not reached by the mower.

Every State highway department should decide upon a definite policy of weed control, equip its forces in accordance with the methods selected and fully instruct its maintenance personnel why and when different operations must be performed. The character of the work and the time it should be done will vary from year to year depending upon the effectiveness of the work of preceding years and how the weather affects the maturing of weed growth.

The objective should be the replacement of all weeds with suitable low growth. Most highway departments now have a landscape architect to supervise roadside-improvement work and his knowledge of plant habits and growth makes it desirable that he have close contact with the planning of weed-control work.

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STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF JANUARY 31, 1937

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 7,872,980	$ 51,600	$ 25,800	9.0	$ 937,481	$ 468,740	36.9	$ 801,590	$ 400,780	46.5	$ 6,977,660
Arizona	5,394,661	1,855,670	1,435,570	102.5	1,059,678	839,446	40.4	508,266	358,421	20.7	2,761,224
Arkansas	6,463,681				690,901	689,793	22.3	1,970,706	1,970,239	109.8	3,803,649
California	14,366,891	5,743,330	3,299,695	148.5	8,297,414	4,754,356	207.8	1,616,266	902,036	41.6	5,410,805
Colorado	6,911,198	3,665,727	1,956,513	146.0	2,954,576	1,632,551	97.3	1,118,551	626,203	60.0	2,695,930
Connecticut	2,388,339	777,897	388,949	14.2	705,928	350,556	8.7				1,648,834
Delaware	1,843,750	439,127	219,348	34.4	292,582	146,030	7.7	407,854	192,008	12.3	1,286,364
Florida	5,020,323	826,514	407,878	27.5	1,075,355	537,673	40.2	1,241,670	620,835	22.3	3,453,937
Georgia	9,569,722	1,145,317	535,720	86.2	2,378,207	1,189,089	124.9	643,840	321,920	30.1	7,522,994
Idaho	4,635,991	2,692,632	1,582,237	256.6	754,240	451,335	52.9	759,789	454,503	40.2	2,147,916
Illinois	15,564,720	8,271,649	4,130,594	134.5	4,435,496	2,183,273	116.3	3,807,885	1,880,790	104.4	7,370,062
Indiana	9,333,269	5,396,075	2,691,320	179.1	2,486,425	1,242,424	65.5	2,919,490	1,459,058	68.1	3,940,466
Iowa	9,757,950	6,859,355	3,330,098	466.7	2,953,216	1,472,725	113.8	2,495,257	1,240,104	79.8	3,715,023
Kansas	10,005,211	2,987,962	1,493,019	606.5	5,098,601	2,522,847	394.6	3,429,964	1,714,964	173.8	4,274,381
Kentucky	6,961,271	2,232,017	1,090,976	149.8	988,987	494,493	28.7	1,234,422	617,210	32.6	4,758,592
Louisiana	5,387,420	1,855,608	925,151	66.1	810,147	405,072	28.0	870,287	430,845	17.6	3,626,352
Maine	3,299,867	1,911,144	954,774	58.7	838,968	419,484	21.7	731,560	365,780	23.6	1,559,829
Maryland	3,094,808				1,069,427	534,678	17.5	442,610	221,305	6.3	2,338,825
Massachusetts	5,255,300	333,935	166,968	3.1	4,322,180	2,161,090	20.3	477,660	238,830	2.3	2,688,412
Michigan	11,562,296	9,135,716	4,531,544	327.9	5,020,619	2,509,406	128.0	957,750	478,250	29.2	4,043,096
Minnesota	10,344,485	8,180,055	3,844,163	532.8	2,320,208	1,160,105	127.2	1,376,989	688,495	46.8	4,651,723
Mississippi	6,635,344				913,040	456,820	55.9	2,677,871	1,338,185	128.3	4,840,339
Missouri	11,479,090	4,065,899	2,028,370	439.3	7,178,579	3,580,796	258.8	2,810,218	1,397,763	115.1	4,472,160
Montana	7,744,061	3,752,814	2,100,650	384.1	2,608,183	1,460,321	172.3	647,433	324,306	29.2	3,858,784
Nebraska	7,809,353	2,740,846	1,368,005	170.2	2,902,005	1,456,585	288.6				4,984,763
Nevada	4,821,864	1,571,360	1,355,536	272.2	567,128	487,083	11.5	9,600	8,300	.5	2,970,945
New Hampshire	1,843,750	857,796	422,345	24.8	192,933	96,014	2.3				1,325,391
New Jersey	5,054,295	2,466,551	1,233,124	34.7	2,257,052	1,051,231	24.9	19,989	9,994		2,759,945
New Mexico	6,030,708	3,414,419	2,097,613	273.2	1,873,692	1,139,563	122.2	146,499	89,100		2,704,432
New York	18,565,567	8,076,035	3,979,167	167.7	14,504,484	6,951,397	226.2	3,801,300	1,339,850	65.4	6,295,153
North Carolina	8,877,837	2,258,254	1,128,251	301.0	3,128,312	1,556,358	230.2	2,670,300	1,220,000	83.7	4,973,228
North Dakota	5,914,683				384,820	204,581	.4				5,710,102
Ohio	13,771,548	2,480,549	1,236,370	44.3	5,838,641	2,761,206	56.5	1,747,550	819,275	20.5	8,954,697
Oklahoma	8,880,547	2,671,532	1,388,452	92.1	1,935,244	1,014,710	75.5	1,131,868	585,100	27.0	5,892,286
Oregon	6,182,079	2,919,052	1,764,466	110.5	2,700,632	1,599,127	115.6	1,187,562	701,448	25.6	2,117,039
Pennsylvania	16,129,804	6,651,795	3,325,205	111.3	7,270,667	3,627,506	99.3	2,964,560	1,475,236	49.9	7,701,857
Rhode Island	1,843,750	213,888	106,944	3.4	678,336	339,168	5.6	173,727	86,864	2.1	1,310,774
South Carolina	5,103,525	216,108	85,500	22.2	3,999,480	1,649,420	255.6	1,104,382	407,700	97.1	2,960,905
South Dakota	6,162,747	1,396,263	784,004	188.6	127,860	80,869	36.5	772,488	423,492	57.4	4,874,382
Tennessee	7,949,330	2,159,870	1,077,805	94.2	695,856	347,923	22.4	885,780	442,890	31.0	6,080,712
Texas	23,500,431	10,972,590	5,470,692	640.4	5,700,331	2,846,035	288.2	8,130,141	3,939,494	505.5	11,250,209
Utah	4,274,740	2,072,641	1,476,890	138.1	922,190	664,334	66.5	273,583	198,217	18.7	1,935,299
Vermont	1,843,750	1,319,301	655,718	62.9	814,359	380,260	23.7	243,300	121,650	8.0	686,122
Virginia	6,887,569	2,752,896	1,373,608	109.8	1,948,680	974,336	101.1	1,824,685	912,343	51.6	3,627,283
Washington	5,907,615	3,881,697	2,038,263	149.9	1,967,306	1,033,271	84.2	543,954	284,800	4.4	2,551,281
West Virginia	4,107,201	785,955	392,977	41.1	816,556	408,266	18.9	737,725	368,862	17.1	2,937,095
Wisconsin	9,197,557	4,098,859	1,966,662	164.7	3,977,710	1,934,584	129.7	748,658	373,275	18.4	4,923,037
Wyoming	4,722,322	2,835,092	1,744,404	354.0	1,127,677	689,037	130.2	728,456	448,624	56.5	1,840,257
Hawaii	1,843,750				537,793	265,921	9.8	421,060	210,195	8.4	1,367,634
Puerto Rico	625,000										625,000
TOTALS	368,750,000	141,023,392	73,611,338	7,744.8	127,065,182	65,221,888	4,613.3	64,415,095	32,709,539	2,389.4	197,207,235

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JANUARY 31, 1937

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$ 4,151,115	$ 3,036,662	$ 3,036,362	97.7	$ 1,042,170	$ 1,042,170	40.6				$ 72,582
Arizona	2,569,841	2,547,433	2,205,206	162.9	526,730	300,064	25.6	$ 100,643	$ 30,137	7.3	34,433
Arkansas	3,352,061	2,497,841	2,480,129	260.5	800,798	798,995	87.6	29,715	29,499	10.9	43,437
California	7,747,928	5,808,360	5,621,952	228.4	2,062,739	2,045,845	26.8				80,131
Colorado	3,395,263	1,970,108	1,961,044	97.9	153,510	153,494	7.0				1,280,725
Connecticut	1,413,709	402,033	382,928	4.3	423,251	397,410	5.1	272,331	256,831	8.1	381,541
Delaware	900,310	417,640	410,683	45.4	451,442	353,856	21.4				135,771
Florida	2,597,144	1,427,880	1,424,043	65.1	1,069,251	1,069,251	34.0	38,957	38,957		64,893
Georgia	4,988,967	479,047	472,243	29.1	831,616	831,616	54.1	266,889	266,889	22.0	3,418,218
Idaho	2,222,747	2,209,717	2,141,178	182.9	56,927	56,927	2.7				24,642
Illinois	8,594,009	7,362,520	7,301,509	418.3	1,352,408	1,352,408	52.9				40,092
Indiana	4,941,255	2,745,166	2,517,673	115.7	2,322,341	2,322,341	112.8	37,925	37,925	6.3	63,317
Iowa	4,991,664	2,569,468	2,477,319	322.3	2,644,540	2,492,895	198.3	37,723	21,450	2.9	
Kansas	4,994,975	2,157,487	2,157,018	226.1	2,849,966	2,831,762	149.0	6,195	6,195	.6	
Kentucky	3,726,271	2,611,265	2,595,839	308.5	719,658	719,658	36.4	213,797	213,788	7.1	196,986
Louisiana	2,890,429	1,095,899	940,741	67.3	1,799,448	1,598,347	97.9	204,077	204,077	9.5	147,264
Maine	1,676,799	1,271,208	1,270,368	55.4	344,642	344,642	15.6	52,100	52,100	1.7	9,689
Maryland	1,750,738	378,205	376,029	17.6	555,725	555,725	10.7	477,247	377,817	12.8	441,168
Massachusetts	3,262,885	203,614	203,614	2.5	2,554,270	2,200,910	15.5	130,110	130,110	.4	728,251
Michigan	6,301,414	6,106,242	6,031,562	287.9	291,871	246,871	4.8	5,765	4,650		18,331
Minnesota	5,277,145	5,171,181	4,391,532	815.7	1,147,311	743,325	85.5	137,137	120,248	2.3	22,039
Mississippi	3,457,552	1,884,824	1,880,934	139.3	1,447,716	1,446,347	92.8	48,500	48,500	3.0	81,772
Missouri	6,012,652	3,436,242	3,399,960	696.1	2,216,469	2,100,512	80.0	523,893	429,968	1.7	82,211
Montana	3,676,416	3,351,841	3,348,936	185.1	245,028	245,028	10.2				82,451
Nebraska	3,870,739	2,235,485	2,192,111	240.1	1,314,598	1,313,095	117.6	114,733	114,733	12.2	250,801
Nevada	2,243,074	1,773,592	1,719,315	79.7	287,205	287,205	12.3	134,698	121,548	.3	115,006
New Hampshire	945,225	655,002	629,312	26.7	180,697	178,504	7.6	108,084	107,219	3.3	30,191
New Jersey	3,129,805	667,788	664,788	14.0	2,310,652	2,297,497	16.9	85,946	76,977	2.9	90,543
New Mexico	2,871,397	2,301,821	2,300,502	179.2	375,715	375,715	13.9	83,314	83,314	5.2	111,866
New York	11,046,377	7,643,658	7,353,467	130.2	3,509,260	3,381,360	37.7	295,300	295,300	2.4	16,250
North Carolina	4,720,173	2,221,485	2,221,485	146.9	2,291,590	2,229,801	121.2	232,071	196,131	10.6	72,755
North Dakota	2,867,245	1,381,290	1,379,329	209.3	1,131,196	1,127,760	96.3	159,667	159,611	20.2	200,545
Ohio	7,670,815	3,043,625	2,983,062	138.2	3,621,427	3,571,031	117.8	966,060	962,530	41.4	154,192
Oklahoma	4,580,670	2,302,597	2,277,659	213.5	1,614,966	1,606,776	149.5	476,141	471,282	30.4	224,953
Oregon	3,038,642	2,054,423	2,035,590	149.3	1,161,326	799,892	8.0	69,992	69,992	9.5	133,169
Pennsylvania	9,347,797	1,816,909	1,751,221	91.0	2,334,510	2,284,672	63.1	1,649,173	1,643,359	51.9	3,668,545
Rhode Island	989,208	990,131	979,535	18.8	9,520	9,520	.6				153
South Carolina	2,702,012	1,017,081	959,962	97.0	1,231,900	1,194,365	118.5	318,449	305,141	16.3	242,543
South Dakota	2,976,454	1,950,262	1,949,444	383.0	734,747	734,747	80.5	93,620	93,620	18.2	198,643
Tennessee	4,192,460	2,200,158	2,193,276	92.0	937,611	937,611	34.6	523,573	523,573	16.6	538,000
Texas	11,989,350	10,695,387	9,749,194	989.2	2,446,619	2,123,997	126.7	76,061	60,475	6.0	55,685
Utah	2,067,154	1,612,126	1,475,251	163.5	431,344	399,980	26.2	90,221	90,221	3.5	101,702
Vermont	924,306	835,878	734,174	20.5	206,848	157,545	1.6	21,062	20,930	.9	11,657
Virginia	3,652,667	2,814,645	2,740,481	904.4	612,103	598,369	109.4	120,635	113,567	27.3	200,249
Washington	3,026,161	2,565,627	2,304,314	157.7	835,386	721,608	6.8				239
West Virginia	2,231,412	484,483	481,279	24.5	1,597,597	1,596,526	65.1	149,621	119,620	5.2	33,987
Wisconsin	4,823,884	4,992,340	4,433,853	328.1	509,195	368,403	15.1				21,629
Wyoming	2,219,155	1,630,454	1,630,369	123.1	542,569	523,701	17.0				65,085
District of Columbia	949,496	930,398	930,398	8.6	19,098	19,098	.2				
Hawaii	926,033	244,040	228,652	4.0	688,277	681,181	13.3				16,201
TOTALS	195,000,000	122,202,568	117,326,825	9,764.5	58,845,783	55,770,358	2,644.8	8,351,425	7,898,284	380.9	14,004,533

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF JANUARY 31, 1937

STATE	APPORTIONMENT	COMPLETED					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS
				NUMBER					NUMBER					NUMBER			
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,034,617	$ 1,922,172	$ 1,922,172	27	1	4	$ 1,907,753	$ 1,907,753	21			$ 10,140	$ 10,140			8	$ 194,552
Arizona	1,256,099	825,527	821,292	9			359,694	348,249	4								86,558
Arkansas	3,574,060	1,322,674	1,318,539	30	4		2,000,062	1,996,729	24	2	1	214,670	214,400	2		28	44,392
California	7,486,362	4,266,035	4,115,169	25	8		3,148,136	3,054,767	19								316,426
Colorado	2,631,567	1,074,662	1,052,372	19			1,132,441	1,132,431	10	1							446,764
Connecticut	1,712,684	73,479	73,479		1		779,991	758,630	5		1	76,314	76,314		1		804,261
Delaware	418,239						130,000	130,000	1								288,239
Florida	2,827,883	1,248,356	1,246,045	10	5		1,139,547	1,139,204	18	1		178,000	178,000	2			264,634
Georgia	4,895,949	30,706	30,706		2		725,457	725,457	16	1		188,098	188,098	7		1	3,951,688
Idaho	1,674,479	899,847	896,674	14	1	2	370,886	370,773	5	1		25,265	25,265			15	381,767
Illinois	10,307,184	3,373,645	3,372,768	40	1		5,572,107	5,428,907	28	5		1,454,100	1,454,100	3	1		51,409
Indiana	5,111,096	1,422,488	1,419,963	17	7		3,445,155	3,322,036	25	5		393,720	363,120			162	5,977
Iowa	5,600,679	1,988,651	[illegible]	49	6		3,417,373	[illegible]	55	3		[illegible]	[illegible]	3		8	22,112
Kansas	5,240,258	774,057	774,057	11		3	4,542,745	[illegible]	47	1		[illegible]	[illegible]			1	
Kentucky	3,672,387	395,465	395,465	8	1		2,358,176	[illegible]	14	2		252,078	252,078	3			[illegible]
Louisiana	3,213,467						1,656,948	[illegible]	12	1		[illegible]	712,247	4	3		[illegible]
Maine	1,426,861	[illegible]	489,812	12		2	584,695	584,103	8			77,464	77,464	1			275,482
Maryland	2,061,751	274,706	274,706	2	3		595,787	595,787	4		17	606,404	583,936	2	2	2	607,323
Massachusetts	4,210,833	884,661	884,661	7	2		2,052,433	2,052,433	16	1		350,743	350,743	1	1		922,996
Michigan	6,765,197	3,322,775	3,278,275	34	4		3,454,277	3,454,277	11	4							32,645
Minnesota	5,395,441	2,846,823	2,715,906	59	9	38	2,509,840	2,323,459	26	3	3	58,428	58,428		1	1	297,647
Mississippi	3,241,475	712,987	712,839	20	3	1	1,874,273	1,874,273	33			15,070	15,070			4	639,293
Missouri	6,142,153	367,844	367,844	7			5,620,522	5,424,278	41	1		367,252	253,300	1		2	96,731
Montana	2,722,327	2,469,975	2,469,470	35	6		178,582	178,582	2								74,275
Nebraska	3,556,441	1,521,673	1,520,188	55	1	1	1,577,178	1,577,178	22	1	5	397,665	397,665	4	1	18	61,410
Nevada	887,260	690,197	690,197	9	1		211,658	193,432	1			3,630	3,630			5	
New Hampshire	822,484	341,748	341,748	3	3		160,490	160,490	4	1	1	264,177	264,132	3			56,114
New Jersey	3,983,826	508,289	508,289	3	2		[illegible]	2,124,361	15	1		542,474	542,474	2	4		808,702
New Mexico	1,725,285	1,010,150	1,010,135	12	1		716,430	713,740	7								1,410
New York	13,577,189	2,273,973	2,269,173	12	8		9,485,651	9,229,605	28	30		1,057,230	1,057,230	1	8		1,021,181
North Carolina	4,823,958	741,865	741,865	12	7		2,751,656	2,732,105	29	9	46	481,680	481,680	7	1	15	868,308
North Dakota	3,207,473	515,132	515,132	16			1,988,284	1,987,284	31	3		343,730	343,730	10	1		361,327
Ohio	8,439,897						5,370,694	5,147,201	34	5		2,560,560	2,403,502	20	2	3	889,194
Oklahoma	5,004,711	1,477,537	1,477,467	30	3		1,784,915	1,784,915	19	3		416,024	416,024	5	3	2	1,326,306
Oregon	2,334,204	878,941	878,451	8	5	2	1,491,605	1,410,005	8	1		34,950	34,950	1			10,798
Pennsylvania	11,483,613	1,705,034	1,560,946	26	6		5,952,432	5,553,640	39	10	9	[illegible]	1,857,444	7	1		2,511,584
Rhode Island	699,691	655,074	654,008	4	1		25,386	25,386		1		39,260	12,812		1		7,485
South Carolina	3,009,956	[illegible]	475,951	12	2	3	1,400,825	1,339,482	25	7		354,682	354,682	4		55	839,841
South Dakota	3,249,036	734,402	734,402	21	1	14	1,444,779	1,444,779	31	3	11	285,205	285,205	8	1	6	784,700
Tennessee	3,903,979	513,125	513,125	10	1	15	1,467,277	1,467,277	21	1	2	1,261,366	1,261,366	10	1	6	662,211
Texas	[illegible]	[illegible]	[illegible]	65	9		6,322,832	6,316,455	63	4		499,270	499,263		1	176	454,605
Utah	1,230,705	87,218	85,828	1	1		1,107,705	1,107,705	16			2,700	2,700			1	34,529
Vermont	729,857	[illegible]	485,556	7	5	10	238,930	194,630	3	1	4						49,671
Virginia	3,774,287	1,524,744	1,453,879	30	6	1	751,170	712,172	7	7		552,742	552,741	13	2	17	1,055,496
Washington	3,095,041	1,014,754	1,009,922	15	5	7	1,824,355	1,823,930	8	6		7,788	7,788			2	253,401
West Virginia	2,077,937						1,549,493	1,549,491	19	3		189,362	189,362	4		4	939,084
Wisconsin	5,022,683	2,031,168	2,003,071	25	4		2,935,206	2,843,954	12	3							175,658
Wyoming	1,360,841	464,745	464,638	6			648,627	648,624	6								247,579
Dist. of Columbia	410,804						425,564	396,204	3								14,000
Hawaii	453,703						522,380	453,703	5								
TOTALS	196,000,000	54,298,084	53,541,764	818	136	103	103,807,808	101,380,638	907	132	100	16,620,886	16,037,162	133	40	542	25,040,436

PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1927. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1928. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1929. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

DEPARTMENT BULLETINS

No. 583D . . Reports on Experimental Convict Road Camp, Fulton County, Ga. 25 cents.

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

TECHNICAL BULLETINS

No. 265T . . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

Federal Legislation and Regulations Relating to Highway Construction. 10 cents.

Supplement No. 1 to Federal Legislation and Regulations Relating to Highway Construction. 5 cents.

No. 191 . . . . Roadside Improvement. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF JANUARY 31, 1937

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,173	$ 4,259,842	$ 15,583,537	$ 8,301,392	$ 3,764,471	770.5	$ 233,955	$ 52,665	$ 181,290	6.4		$ 285,322	1.5	$ 16,076	$ 28,258
Arizona	5,211,960	2,641,435	8,981,820	5,204,512	2,505,035	542.9	12,500		12,500					7,448	24,400
Arkansas	6,748,335	3,428,049	10,949,302	6,631,424	3,347,962	619.9	139,416	70,019	62,922	3.9	$ 41,829	7,200	13.5	5,003	9,965
California	15,507,354	7,932,206	30,627,453	15,583,732	7,768,675	758.7	115,898		115,336					23,572	47,695
Colorado	6,874,530	3,436,006	11,233,637	6,873,735	3,459,071	639.0	6,362		6,360					795	20,576
Connecticut	2,865,740	1,454,868	4,514,512	2,758,269	1,312,770	74.0	59,618	59,618		.1				47,854	142,098
Delaware	1,819,088	923,395	2,733,715	1,818,804	868,109	128.8	49,363		49,363	1.2				284	5,923
Florida	5,231,834	2,661,343	8,910,496	5,175,534	2,344,563	305.6	332,979		308,665	4.0	56,300		.5		8,116
Georgia	10,091,185	5,113,491	13,294,173	9,269,813	3,256,698	754.2	1,013,512	408,690	604,822	72.2	84,072	218,875	3.1	328,611	1,033,096
Idaho	4,486,249	2,277,486	7,098,072	4,477,339	2,135,517	501.4	54,194		52,034	.1		1,886		8,910	38,049
Illinois	17,570,770	8,921,401	26,228,301	17,132,552	7,998,840	715.4	1,337,417	325,149	885,007	13.5	17,560	7,100	7.5	45,509	30,453
Indiana	10,037,843	5,088,963	15,472,436	9,896,355	4,803,874	479.1	267,993	129,083	138,910	5.7		58,728		12,405	87,452
Iowa	10,055,660	5,118,361	15,455,458	10,055,161	4,797,361	1,222.2	340,072		321,000	5.1	499				
Kansas	10,089,604	5,117,675	15,427,787	10,089,600	5,010,191	1,132.3	110,336		86,598	13.1				4	20,885
Kentucky	7,517,359	3,318,311	12,036,657	7,504,619	3,574,952	811.3	205,881		205,881	4.2	10,217	27,540		2,523	9,838
Louisiana	5,828,591	2,963,932	9,168,831	5,787,557	2,718,108	259.5	215,480		215,459	11.5				41,034	30,365
Maine	3,369,917	1,711,586	5,253,290	3,347,261	1,676,308	193.5	43,100	15,000	26,540	1.4				7,655	8,738
Maryland	3,564,527	1,810,058	5,653,409	3,475,517	1,103,885	152.2	68,343		68,343	1.5		285,453	7.3	88,910	352,377
Massachusetts	6,597,100	3,350,474	10,383,667	6,552,734	3,094,370	115.5						91,944	.1	44,366	164,160
Michigan	12,736,227	6,452,568	20,694,553	12,736,227	6,306,320	768.1	96,788		96,788			40,000	.4		9,460
Minnesota	10,656,569	5,425,551	16,235,971	10,514,422	4,870,955	1,641.9	374,082	58,110	270,314	7.2		34,800	.6	84,037	249,482
Mississippi	6,978,675	3,540,227	12,728,665	6,763,926	2,934,079	723.3	674,062	165,696	491,245	21.9	3,960	15,123	.8	45,092	39,780
Missouri	12,180,306	6,173,740	18,179,234	12,105,337	4,962,661	1,441.2	1,130,984		1,127,050	6.4		27,356		74,969	56,673
Montana	7,439,748	3,769,734	11,754,936	7,425,476	3,644,311	1,058.4	56,546		56,546					14,273	63,877
Nebraska	7,828,961	3,964,364	12,837,282	7,812,918	3,613,533	1,018.4	272,820		265,495	27.7		68,900	5.9	16,043	16,437
Nevada	4,545,917	2,302,356	7,065,551	4,545,917	2,268,591	758.8	25,004		25,004			1,650			7,111
New Hampshire	1,909,839	969,462	3,003,039	1,904,951	950,488	78.3	4,174		4,174					4,888	14,800
New Jersey	6,346,039	3,220,879	9,096,652	6,045,652	2,452,166	85.9	1,218,088	120,518	663,430	10.3	88,486	9,212	.6	91,384	96,071
New Mexico	5,792,935	2,941,700	8,784,010	5,731,884	2,813,448	743.9	107,130		107,130	5.9		2,695		61,051	18,426
New York	22,330,101	11,327,921	39,446,868	21,773,149	10,433,822	821.3	1,131,180	416,110	631,049	2.6	139,503	139,675	1.4	1,339	63,374
North Carolina	9,522,293	4,840,941	14,957,895	9,210,800	4,520,731	1,345.8	582,880	291,910	257,207	19.6				19,582	63,004
North Dakota	5,804,448	2,938,967	8,612,636	5,593,423	2,250,890	2,127.0	230,303	106,183	124,120	16.3	15,703	153,680	27.6	89,139	410,276
Ohio	15,484,592	7,865,012	24,746,655	15,379,719	7,519,093	792.1	276,268	40,500	206,351	4.0	34,023	87,639	4.3	30,350	51,429
Oklahoma	9,216,798	4,685,180	14,628,257	9,212,943	4,313,159	805.5	105,855		105,855	1.1		174,301	.2	3,855	91,864
Oregon	6,106,896	3,097,814	9,901,295	6,037,198	2,940,828	468.0	75,530	11,308	64,222	.8	55,000	26,981	.7	3,391	65,783
Pennsylvania	18,891,004	9,590,788	28,769,339	18,536,705	8,741,885	1,053.5	473,357	53,214	377,896	3.1	168,454	190,960	4.6	132,630	280,048
Rhode Island	1,998,708	1,014,572	3,150,270	1,998,708	1,012,094	89.1									2,478
South Carolina	5,459,165	2,770,954	7,999,242	5,222,052	2,460,815	618.6	359,440	161,981	196,174	9.5	46,320	60,613	1.7	28,812	53,353
South Dakota	6,011,479	3,047,543	9,267,271	5,834,666	2,856,363	1,571.5	207,802	77,600	130,202	29.5		26,146	6.1	99,213	34,933
Tennessee	8,492,619	4,302,991	13,667,902	8,490,706	4,135,256	492.7	102,910		102,910	3.6		46,727	5.9	1,913	18,098
Texas	24,244,024	12,291,253	37,992,724	24,139,662	11,882,478	2,780.0	97,693	14,797	82,576	.7		211,401	8.5	39,565	114,797
Utah	4,194,708	2,132,691	7,408,593	4,193,208	2,132,691	590.9								1,500	
Vermont	1,867,573	948,007	3,166,359	1,867,452	940,847	141.0								121	7,160
Virginia	7,416,757	3,765,387	11,635,946	7,292,347	3,402,105	614.5	298,632	82,461	210,539	30.5	9,045	64,762	3.7	32,903	81,982
Washington	6,115,867	3,106,412	9,399,840	6,112,042	3,027,370	302.7	46,596		46,596			14,823	.3	3,825	17,622
West Virginia	4,474,234	2,280,335	6,474,665	4,342,391	1,796,306	212.9	375,487	54,892	297,549	9.4		66,425	.7	76,981	120,055
Wisconsin	9,724,881	4,941,837	15,438,317	9,720,705	4,895,799	619.7					4,176	15,050			30,988
Wyoming	4,501,327	2,287,712	6,891,444	4,451,923	2,230,541	1,037.7	5,781	5,780		.3	11,818	21,300	2.5	11,806	35,871
District of Columbia	1,918,469	973,842	2,887,584	1,918,469	968,979	22.3						4,863			
Hawaii	1,871,062	949,778	2,680,983	1,857,812	264,953	51.1	650,838		646,859	4.7		14,000		13,250	23,966
TOTALS	394,000,000	200,000,000	628,582,031	388,808,910	183,365,317	35,052.1	13,586,649	2,721,284	9,929,311	359.0	786,965	2,503,730	110.0	1,082,841	4,201,642

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